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URS 686-4

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DEBRIS MODEL RESEARCH
AND
FIVE-CITY STUDY APPLICATIONS

FINAL REPORT

June 1968

OCD Work Unit 3312B

Contract Number 12471(6300A-310)

URS SYSTEMS
CORPORATION

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DEBRIS MODEL RESEARCH AND FIVE-CITY STUDY APPLICATIONS

FINAL REPORT

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OCD Work Unit 3312B

Contract Number 12471(6300A-310)

by

James E. Edmunds
Patrick M. Sears

URS RESEARCH COMPANY
1811 Trousdale Drive
Burlingame, California 94010

Prepared for

OFFICE OF CIVIL DEFENSE
Office of the Secretary of the Army
Washington, D.C. 20310

OCD REVIEW NOTICE

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

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Summary
URS 686-4

URS SYSTEMS CORPORATION

DEBRIS MODEL RESEARCH AND FIVE-CITY APPLICATIONS

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Summary Report

of

DEBRIS MODEL RESEARCH AND FIVE-CITY APPLICATIONS

INTRODUCTION

This report is a continuation of research to develop methods to predict depths of debris resulting from a nuclear-weapon attack on a city. The report contains refinements of the debris prediction model developed in previous work and application of this model for the Office of Civil Defense Five-City Study.

The refinements consist of expanding the coverage of the debris prediction curves to a larger number of weapon yields. The damage to wood frame buildings was also examined in some detail to determine if the assumption that their debris production characteristics are independent of yield is valid. As an aid to its application, the debris prediction model was programmed for use with a digital computer, and an explanation of this program is contained in the report.

Damage predictions to various categories of structures for several attack conditions were made for use by the Dikewood Corporation in their casualty estimation procedures. The results are tabulated in the report.

Debris depths resulting from the Five-City Study attack on Albuquerque were predicted and are included in the report in overlay form. Also, damage predictions for selected buildings in Albuquerque were made and put into the Five-City Study Data Bank. Examples of these predictions are included in the report.

DEBRIS CHARTS

The debris charts were originally developed for two weapon yields, 20 kt and 20 Mt. A portion of this contract's effort was directed towards expanding the coverage of these charts to the additional yields of 100 kt, 500 kt, 1 Mt, 10 Mt, and 50 Mt. The building categories were also refined slightly, so that

a differentiation exists between a heavy reinforced concrete shearwall building, which was common in Japan and is rare in this country, and a shearwall building as found in this country, which has less massive construction and is from 3 to 8 stories high.

A computer code developed by T. Y. Lin and Associates for OCD was utilized to describe the response of the building to the blast forces. This code gives the ductility ratios of the structural members due to the blast loading. The ductility ratios were plotted as a function of the overpressure, and the point of building collapse was taken to be the point at which the curve was so steep that a slight increase in overpressure caused a greatly disproportionate increase in the ductility ratio of the ground floor columns. This procedure was utilized to construct the multiyield debris charts for the steel or reinforced concrete frame buildings, both nonearthquake and earthquake design. The shearwall buildings were analyzed using data from previous URS reports.

This task brought to light some differences between severe damage overpressures as predicted by the code and those predicted by TM 23-200 (The Capabilities of Nuclear Weapons). For some categories, the code predicts that severe damage will occur at much lower overpressures than does TM 23-200.

WOOD FRAME BUILDINGS

The damage and debris production characteristics of wood frame buildings has always been assumed to be independent of weapon yield. In this task, pertinent data from nuclear weapons tests were examined, and structural calculations were performed to determine the validity of this assumption.

It was determined that, with the present state of knowledge of the response of wood frame structures to blast loading, there was no basis for changing the debris curve to show yield dependency.

DEBRIS PREDICTION CODE

The debris prediction model was programmed in FORTRAN IV. The inputs for the model are obtained from Sanborn Maps and from the weapon parameters. The output of the model consists of debris depths for an area which is specified as part of the input. The debris charts and building material and contents volume factors are a part of the program.

DIKEWOOD DAMAGE PREDICTIONS

URS furnished the Dikewood Corporation with overpressures for moderate and severe damage and for collapse for several structure categories and for various weapon yields and heights of burst. The structure categories were:

- Curtain wall buildings (reinforced concrete or steel frame)
- Middle floors of curtain wall buildings
- Basements of curtain wall buildings
- Aseismic (designed for earthquake forces) curtain wall buildings (reinforced concrete or steel frame)
- Middle floors of curtain wall buildings (aseismic design)
- Basements of curtain wall buildings (aseismic design)
- Multistory wall-bearing masonry buildings (collapse only)
- Wood-frame buildings (collapse only)
- Light steel-frame industrial buildings (collapse only)
- Heavy steel-frame industrial buildings (collapse only)

The weapon yields considered were 12.5 kt (chosen to enable Dikewood to apply their scaling procedures), and 1, 5, 10, 25, and 50 Mt, all at scaled heights of burst of 0, 300, 585, 806 ft, and directly overhead.

ALBUQUERQUE DAMAGE AND DEBRIS PREDICTIONS

Debris depth predictions were made for the Five-City Study attack on Albuquerque. The attack specified a 5-Mt weapon at 14,500-ft, placed so that the downtown area received between 3 and 4 psi. The debris depths were predicted for both blast only, and for blast combined with fire. The maximum depth in the blast-only case was 6 in. and the maximum depth for both blast and fire was 1 ft- 6 in. The debris depth predictions are presented in the report in map form, and are in the Five-City Study Data Bank as 1:24000 scale overlays.

As part of the contract, damage descriptions were prepared for sample buildings in Albuquerque. The sample buildings were chosen to be representative examples of those types found in Albuquerque. These damage descriptions are of a general, not specific, nature. The descriptions are in a separate document that is in the Five-City Study Data Bank as DB 68-1055; Building Damage Predictions for Albuquerque.

ABSTRACT

This report is a continuation of research into the prediction of debris depths resulting from a nuclear attack. It also contains an application of the debris prediction method to Albuquerque in support of the Five-City Study.

The Five-City work consists of predicting debris depths and building damage for the city of Albuquerque. The debris depth predictions are presented in reduced scale in this report, and are in the Five-City Study Data Bank in the standard 1:24000 scale. The building damage predictions are in the Data Bank as a seperate document, with examples included in this report.

Damage predictions for various categories of structures and for several attack conditions were furnished to The Dikewood Corporation, and are tabulated herein together with a correlation of URS categories with Dikewood categories.

The debris charts were expanded to cover a larger number of weapon yields — from 20 kt to 50 Mt. The debris prediction for the wood-frame building category was examined to determine whether or not the debris production is independent of weapon yield, as has been assumed.

The debris prediction model was programmed for use with a digital computer, which greatly increases the efficiency of the debris prediction process. An explanation of the program is included in the report.

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Section 1
INTRODUCTION

The efforts reported herein are a continuation of research to develop methods to predict the amount of debris resulting from a nuclear weapon attack on an urban area. In previous reports (Refs. 1-4) a model to predict debris depths was developed and refined. During this reporting period the model has been generalized and used to determine debris depths throughout a city.

The model employs "debris charts" relating percent debris and incident overpressure; the generalization consisted of expanding the number of weapon yields covered in the debris charts so that they may be applied to virtually all yields. Also, the response of wood-frame buildings to blast was analyzed to determine whether or not the damage to this structure type is dependent on weapon yield.

To make the computations involved in applying the debris prediction model less time consuming, the model was programmed so that it could be used on a digital computer.

Along with debris depth predictions, URS has been making general predictions of building damage resulting from nuclear attack based on all of the damage data gathered in connection with the construction of the debris charts. All of this information was gathered together and published in a handbook, in order that others might use it to make their own damage predictions. An explanation of the development and use of the debris charts is also included.

Two tasks were accomplished in support of the Five-City Study being carried on by the Office of Civil Defense. The overall debris depths for the city of Albuquerque were calculated and presented in the form of overlays. Also, for Albuquerque, representative buildings were selected and the damage to these buildings was described. An analysis of damage to several building categories under varying attack conditions was performed and furnished to The Dikewood Corporation, to assist them in their casualty predictions for the Five-City Study.

Section 2
DAMAGE PREDICTIONS FOR THE DIKEWOOD CORPORATION

The Dikewood Corporation has the responsibility of furnishing personnel casualty predictions as part of the Five-City Study. In order to predict casualties for persons in buildings, they have related casualties to levels of building damage, i.e., light, moderate, severe, and collapse. Dikewood has developed this information for some structure categories; however, there were a number of categories for which Dikewood did not have adequate damage information. As part of this phase of the contract, URS provided Dikewood with damage descriptions for the following structure categories:

- Curtain wall buildings (reinforced concrete or steel frame)
- Middle floors of curtain wall buildings
- Basements of curtain wall buildings
- Aseismic (designed for earthquake forces) curtain wall buildings (reinforced concrete or steel frame)
- Middle floors of curtain wall buildings (aseismic design)
- Basements of curtain wall buildings (aseismic design)
- Multistory wall-bearing masonry buildings (collapse only)
- Wood-frame buildings (collapse only)
- Light steel-frame industrial buildings (collapse only)
- Heavy steel-frame industrial buildings (collapse only)

The descriptions were in the form of the overpressure necessary to cause moderate or severe damage, or to cause collapse. The weapon yields considered were 12.5 kt (chosen to enable Dikewood to apply their scaling procedures), and 1, 5, 10, 25, and 50 Mt, all at scaled heights of burst (HOB) of 0, 300, 585, 806 ft, and directly overhead.

The overpressures were determined by using the overpressures for moderate

and severe damage that are found in TM 23-200 (Ref. 5), and using the overpressures for collapse (100 percent debris) from a previous URS report (Ref. 2) concerning debris prediction. These collapse overpressures were assumed to be for horizontal flow conditions, so the values had to be changed for the high air bursts. They were changed by the same percentages that the overpressures necessary for severe damage were found to change in TM 23-200. For example, if the overpressure necessary for severe damage from 1-Mt weapon was 10 percent greater at a scaled 585-ft HOB than at a scaled 300-ft HOB, the collapse overpressure was also increased by 10 percent. The damage overpressure for the basements were estimated from the information contained in Refs. 6 and 7, and is unchanged for the various HOB's and weapon sizes and building categories. This is because the damage to the basements is caused by the collapse of the basement ceiling due to a differential pressure between the basement and the first floor, and not by dynamic pressure. The damage to the basement shelters in wood-frame houses was related to the damage to the house itself. This was done because of uncertainties* that would be involved in determining the blast response of the shelter and because the shelter would be damaged not only by the air blast, but also by the house collapsing around it.

Some mention was made of the question of overturning by refering to the curves and discussion on this subject contained in Ref. 4. Dikewood also raised the question of a "piston effect",** i.e., the curtain walls breaking free at their edges and acting as a piston to sweep everything through the building and out the other side. There is a possibility that the connections between the wall panel and building would break in such a manner as to allow the panel to remain intact. However, the path of the panel through the building will be obstructed by partitions, contents, columns, elevator cores, etc., so that it is quite unlikely that the panel will remain intact for more than the first few feet of its travel, thus making the probability of a "piston effect" occurring insignificant.

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* Some of the uncertainties would be the particular type of shelter used, its orientation in the basement with respect to the blast wave's travel, and the openings through which the blast wave would fill the basement.

** Dikewood outlined their problem areas in a letter sent to OCD.

Table 1 contains the damage criteria developed for The Dikewood Corporation.

Table 2 correlates the building type categories that Dikewood uses in its casualty predictions with the categories that URS uses in its debris predictions.

Table 1*

DIKEWOOD DAMAGE CRITERIA

CURTAIN WALL BUILDINGS (steel or reinforced concrete frame) - ASEISMIC					
	SCALED HOB Overpressure (psi)				
WEAPON YIELD	0	300	585	806	OVERHEAD
MODERATE					
12.5 kt	20.0	16.8	21.5	15.7	15.0
1 Mt	13.7	12.2	14.8	12.7	15.0
5 Mt	12.7	11.4	13.7	12.0	15.0
10 Mt	12.3	11.1	13.3	11.7	15.0
25 Mt	11.8	10.7	12.8	11.3	15.0
50 Mt	11.5	10.4	12.2	11.0	15.0
SEVERE					
12.5 kt	35.0	27.7	35.8	22.1	25.0
1 Mt	20.5	16.9	21.0	18.2	25.0
5 Mt	18.0	15.3	18.6	17.0	25.0
10 Mt	17.2	14.8	17.8	16.6	25.0
25 Mt	15.8	14.0	17.2	15.9	25.0
50 Mt	15.0	13.5	16.8	15.4	25.0
COLLAPSE					
12.5 kt	42.5	33.5	42.0	25.9	35.0
1 Mt	22.5	19.0	23.2	20.0	35.0
5 Mt	19.4	16.7	20.3	18.5	35.0
10 Mt	18.2	15.8	19.2	17.8	35.0
25 Mt	16.7	14.8	17.7	16.9	35.0
50 Mt	15.5	13.8	17.1	16.2	35.0

Middle Floors: Same as overall building

Basements:

Moderate: 7.5
Severe: 10.0
Collapse: 15.0

* Although the overpressure values in this table are listed to one decimal place, a more realistic value would be obtained by rounding off to the closest whole number.

Table 1 (cont.)

CURTAIN WALL BUILDINGS (steel or reinforced concrete frame)					
	SCALED HOB Overpressure (psi)				
WEAPON YIELD	0	300	585	806	OVERHEAD
MODERATE					
12.5 kt	12.4	11.8	14.5	12.7	15.0
1 Mt	8.3	8.6	10.1	9.7	15.0
5 Mt	8.2	8.0	9.8	9.5	15.0
10 Mt	8.1	8.0	9.7	9.4	15.0
25 Mt	8.1	8.0	9.5	9.3	15.0
50 Mt	8.0	8.0	9.5	9.2	15.0
SEVERE					
12.5 kt	24.3	18.3	24.5	23.0	25.0
1 Mt	12.9	12.5	14.5	12.3	25.0
5 Mt	11.5	11.8	13.2	11.3	25.0
10 Mt	11.0	11.7	12.7	11.0	25.0
25 Mt	10.4	11.3	12.3	10.7	25.0
50 Mt	10.0	11.2	11.7	10.5	25.0
COLLAPSE					
12.5 kt	36.0	27.7	32.5	*	35.0
1 Mt	18.0	15.8	19.2	15.7	35.0
5 Mt	15.7	14.1	17.5	13.5	35.0
10 Mt	14.8	13.5	16.8	12.2	35.0
25 Mt	13.7	12.7	16.1	11.2	35.0
50 Mt	13.0	12.0	15.5	10.8	35.0

Middle Floors: Same as overall building

Basements:

Moderate: 7.5
Severe: 10.0
Collapse: 15.0

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* Insufficient

Table 1 (cont.)

MULTISTORY, WALL-BEARING MASONRY BUILDINGS					
	SCALED HOB Overpressure (psi)				
WEAPON YIELD	0	300	585	806	OVERHEAD
	TOTAL COLLAPSE				
*	9.5	9.5	9.5	9.5	12.5

WOOD-FRAME BUILDINGS					
	SCALED HOB Overpressure (psi)				
WEAPON YIELD	0	300	585	806	OVERHEAD
	TOTAL COLLAPSE				
*	5.0	5.0	5.0	5.0	5.0

LIGHT STEEL-FRAME INDUSTRIAL BUILDINGS**					
	SCALED HOB Overpressure (psi)				
WEAPON YIELD	0	300	585	806	OVERHEAD
	TOTAL COLLAPSE				
12.5 kt	17.0	19.8	17.7	16.0	185
1 Mt	9.7	11.7	12.1	11.8	185
5 Mt	9.0	10.9	10.9	10.7	185
10 Mt	8.7	10.6	10.6	10.3	185
25 Mt	8.4	10.3	10.0	9.6	185
50 Mt	8.2	10.1	9.4	9.1	185

HEAVY STEEL-FRAME INDUSTRIAL BUILDINGS**					
	SCALED HOB Overpressure (psi)				
WEAPON YIELD	0	300	585	806	OVERHEAD
	TOTAL COLLAPSE				
12.5 kt	20.8	19.0	23.3	18.3	235
1 Mt	14.0	15.0	17.5	15.8	235
5 Mt	13.0	14.4	16.7	15.3	235
10 Mt	12.7	14.3	16.5	15.0	235
25 Mt	12.3	14.0	15.9	14.7	235
50 Mt	12.0	13.8	16.1	14.5	235

* Overpressure is the same for all yields.

** The seemingly excessive overpressures for the overhead weapons are due to the almost strictly drag sensitive nature of these buildings. However, as dynamic pressures are very small for overhead bursts, collapse is due to overpressure effects.

Table 2

BUILDING CATEGORIES

EFFECTS OF NUCLEAR WEAPONS	DIKEWOOD	URS
Wood frame building, house type; 1 or 2 stories	Wood frame	Wood frame
Multistory wall-bearing building, brick apartment house type; up to 3 stories	Brick	Load bearing Masonry
Multistory wall-bearing building, monumental type; up to 4 stories		Load Bearing Masonry
Multistory reinforced concrete building with concrete walls, small window area; 3 to 8 stories		Multistory rein-forced concrete Shearwall Bldg.
Light steel frame industrial building, single story, with up to 5 ton crane capacity	Light steel frame (≤ 2 stories)	Light steel frame industrial
Heavy steel frame industrial building, single story, with 25-50 ton crane capacity		Medium steel frame industrial
Heavy steel frame industrial building, single story, with 60-100 ton crane capacity	Heavy steel frame (≤ 2 stories)	Heavy steel frame industrial
Multistory steel frame office type building, 3-10 stories (non-earthquake resistant construction).	Light steel frame (> 2 stories)	Multistory steel or reinforced con-crete frame building Non-earthquake design.
Multistory steel frame office type building, 3-10 stories (earthquake resistant construction)	Heavy steel frame (> 2 stories)	Multistory steel or reinforced con-crete frame building Earthquake design
Multistory reinforced concrete frame office type building, 3-10 stories (non-earthquake resistant construction).	Non-seismic reinforced concrete	Multistory steel or reinforced concrete frame building. Non-earthquake design
Multistory reinforced concrete frame office type building, 3-10 stories (earthquake resistant construction).	Seismic rein-forced concrete	Multistory steel or reinforced concrete frame building Earthquake design

Section 3
ALBUQUERQUE DEBRIS DEPTH CALCULATIONS

Albuquerque, New Mexico is one of the cities in the OCD Five-City Study, and as such the debris depths resulting from the assumed Five-City attack were calculated. The attack weapon parameters were a 5-Mt yield at a 14,500-ft HOB located to the southeast of the city, such that the downtown area received between 3 and 4 psi (Fig. 1).

The debris depths for Albuquerque were calculated both for blast only and for the combined effects of blast and fire. No attempt was made to delineate the boundaries of the fire spread. The depths were determined in accordance with essentially the same methodology developed and used previously for other cities of the Five-City Study (Detroit and San Jose - Refs. 3 and 4, respectively). Briefly, the methodology determines the volume of material in a structure and its contents. Then, by use of debris charts, the percent of this material that becomes debris as a function of overpressure is determined. This volume of debris is evenly distributed over a specified area. This method is most applicable to a number of buildings rather than a single structure, so that the debris volumes for all of the buildings in a block are summed up to give one uniform debris depth for the block.

One change was made, however, in the method of determining the debris depths after fire. In the prior studies, for the combined blast and fire case, unreinforced load-bearing masonry buildings were said to produce more debris since fire would burn out the floors, thereby removing the lateral support from the walls and causing them to collapse. Although this assumption is still valid, increasing the general depth of debris due to this distorts the debris problem, because this fire-caused debris will be deposited on, or quite close to, the building site. For this reason, unless the load-bearing wall building was adjacent to the street and/or more than one story, the debris resulting from fire was not distributed off the building site. This has the effect of decreasing the debris depths due to fire in all but the downtown, built-up area.

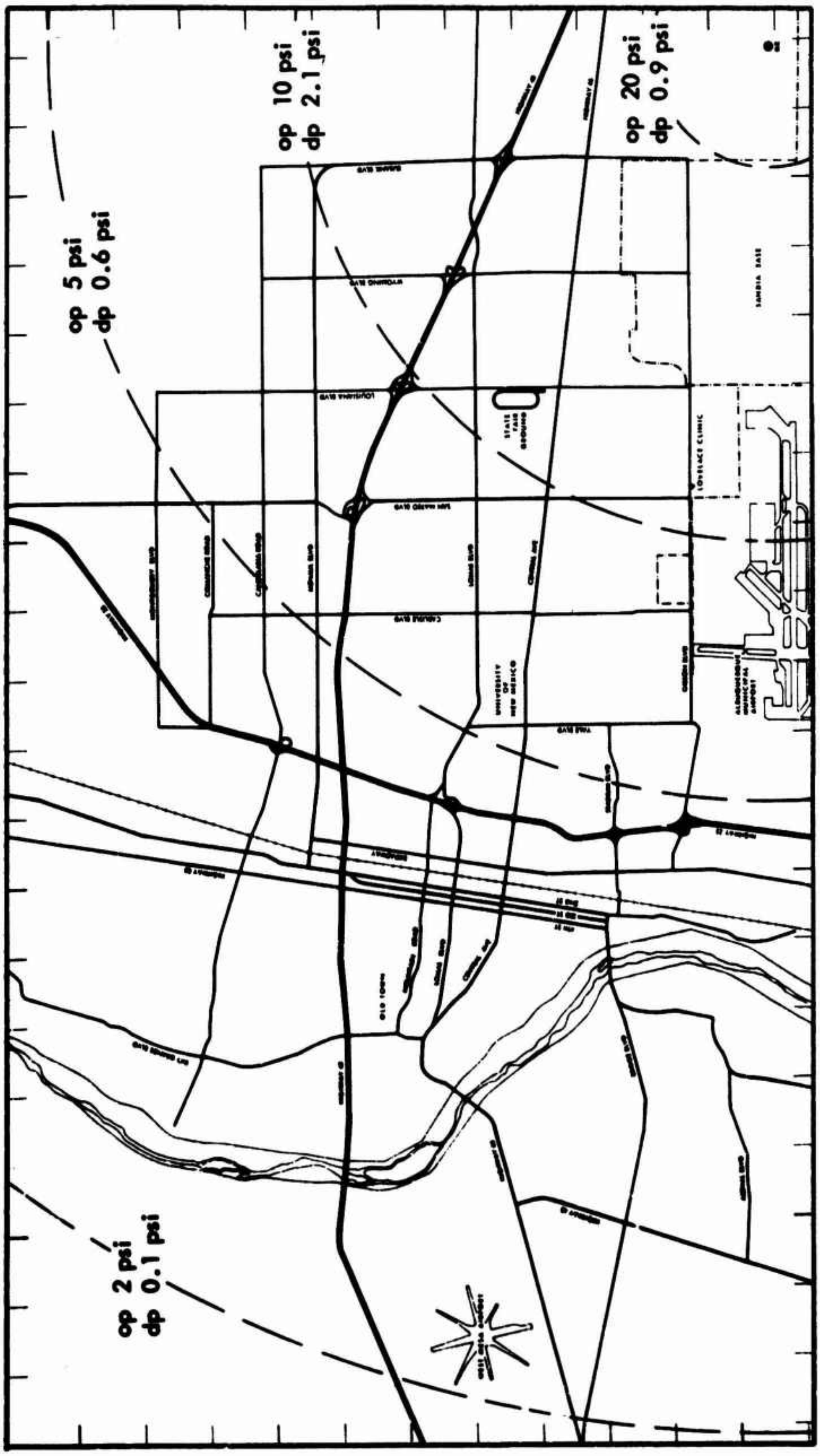


Fig. 1. Overpressure (op) and Dynamic Pressure (dp) Isobars for Albuquerque

The same reasoning would hold true for a wood-frame residence, where more debris would be produced by a fire with no overpressure than by low overpressures with no fire, but the fire-caused debris would be adjacent to the building site and, hence, offer no restriction to travel on the street.

The Sanborn Map coverage of Albuquerque was not as complete in the residential areas as would be desirable, so that an area that was not covered by the Sanborn Maps had to be related to an area that was covered, in order for the debris depth to be calculated. Also, the aerial photographs that were used to help determine the depth of debris were taken in 1954, and the U.S. Geological Survey quadrangle map was dated 1960; thus these two sources of information were not as current as would be desirable. These factors made the on-site reconnaisance invaluable.

The debris depth overlays are in Appendix A, in reduced form. This appendix also contains general descriptions of the debris characteristics for the sample areas of Albuquerque that were used to construct the debris contours, and building damage descriptions together with their associated ground ranges for the Albuquerque weapon.

Descriptions of building damage were prepared for 29 buildings in Albuquerque. These buildings were chosen to be representative examples of those types found in Albuquerque. The damage descriptions are of a general nature, that is, they are not detailed descriptions of the damage, but rather a qualitative summary. For instance, the damage was described by giving the percent of the exterior walls which were destroyed, instead of stating that specific sections of the exterior walls were blown in. These descriptions are in a separate report that is in the Five-City Study Data Bank as DB 68-1055: Building Damage Predictions for Albuquerque.

Section 4
COMPUTER PROGRAM

GENERAL

The manual application of the debris model to determine debris depths for a large area is a tedious and time-consuming task. All of the building information contained on the Sanborn Map sheet must be transferred to a worksheet and then the debris volumes calculated. The determination of the debris volume entails: calculating the volume of the structural material (from the building's dimensions and the material coefficient for the structure types); determining the percent debris from the debris charts; and applying this percent to the volume of the material in order to determine the debris volume. Because these steps are of a repetitive nature, they were incorporated into a computer program in order to increase speed and efficiency.

In general terms, the basic program consists of:

- Tables to determine the factor for calculating material volume (based on building type)
- Tables to determine the factor for calculating contents volume (based on building occupancy)
- Series of IF statements to determine percent debris, as a function of incident overpressure, for a given structure type and weapon yield
- Routines for calculating debris volumes and, using a specified area, determining debris depths

The program will consider blast along or blast combined with fire. It can be set up to determine debris depths for an area or along a route. The input takes the form of:

- Plan area, height, and number of stories
- Building construction category
- Building occupancy category

- Incident overpressure
- Weapon yield
- Fire or no fire
- Area over which debris is to be distributed (usually all buildings in one block are considered together)

All of the input data may be read from a Sanborn Map, excluding, of course, the attack parameters.

DEBRIS CHARTS

The characteristic shape of the majority of the debris charts (an initial rising limb, a plateau and a final rising limb) made it quite simple to program these. They were broken down into straight-line segments that were defined by end points located by an overpressure and a percent debris. A sequence of IF statements was used to determine the segment into which the incident overpressure fell. Once the proper segment was found, the equation for a straight line, $y = mx + b$, was used to determine the exact percent debris, where y is the percent debris.

The slope, m, is determined by the end points of the particular segment. The value of x is determined by the difference between the incident overpressure and the value of the lesser end point overpressure. The value b is determined by the lesser end point percent debris.

There are 21 different structure categories in the computer program, and each of these categories can have as many as 18 different curves, depending on weapon yield and presence or absence of fire. The proper category and curve are specified by the use of subscripts.

INPUT-OUTPUT

The first block of data for the debris code consists of the debris curves. In the code's present form, all building categories, weapon yields, and fire or no-fire debris curves are read in as data.

The second block of data consists of curves to determine the percent of the building's contents that become debris. There is no curve for each building type.

The third block of data identifies the number of areas, the number of buildings in each area, the size of the area, and the building and furnishing parameters.

The formats for the program inputs are as follows:

1. 1st Block of Data - Debris Curves
   FORMAT (10 F 5.1)

2. 2nd Block of Data - Contents Curves
   FORMAT (3 F 5.1)

3. 3rd Block of Data - Area and Building Parameters
   KK = Number of Areas (block or other area - 10 maximum)
   FORMAT (I 3)

   UA (K) = Area (ft^2) K (K = 1, 10)
   FORMAT (F 5.1, I 3)

   JJ1 = 1, 21 for weapon size, fire and no fire
   FORMAT (I 3)

   XPP (J, K) = Overpressure at Building J in Area K

   UL (J, K) = Length of Building J in Area K

   UW (J, K) = Width of Building J in Area K

   UH (J, K) = Height of Building J in Area K

   NN = Number of stories in Building J in Area K

   MM = -1 no fire
   +1 fire

   L1 = Structure type of Building J in Area K (1 to 20)

   L2 = Occupancy Category (1 to 18)
   FORMAT 4F5.1, 4I3

The third block of data is written out just as it was put in for checking. The area number, area, and debris depth for the area are then printed out.

Figure 2 is the flow chart for the computer program. Figure 3 is the actual listing of the program.

The program language is FORTRAN IV.

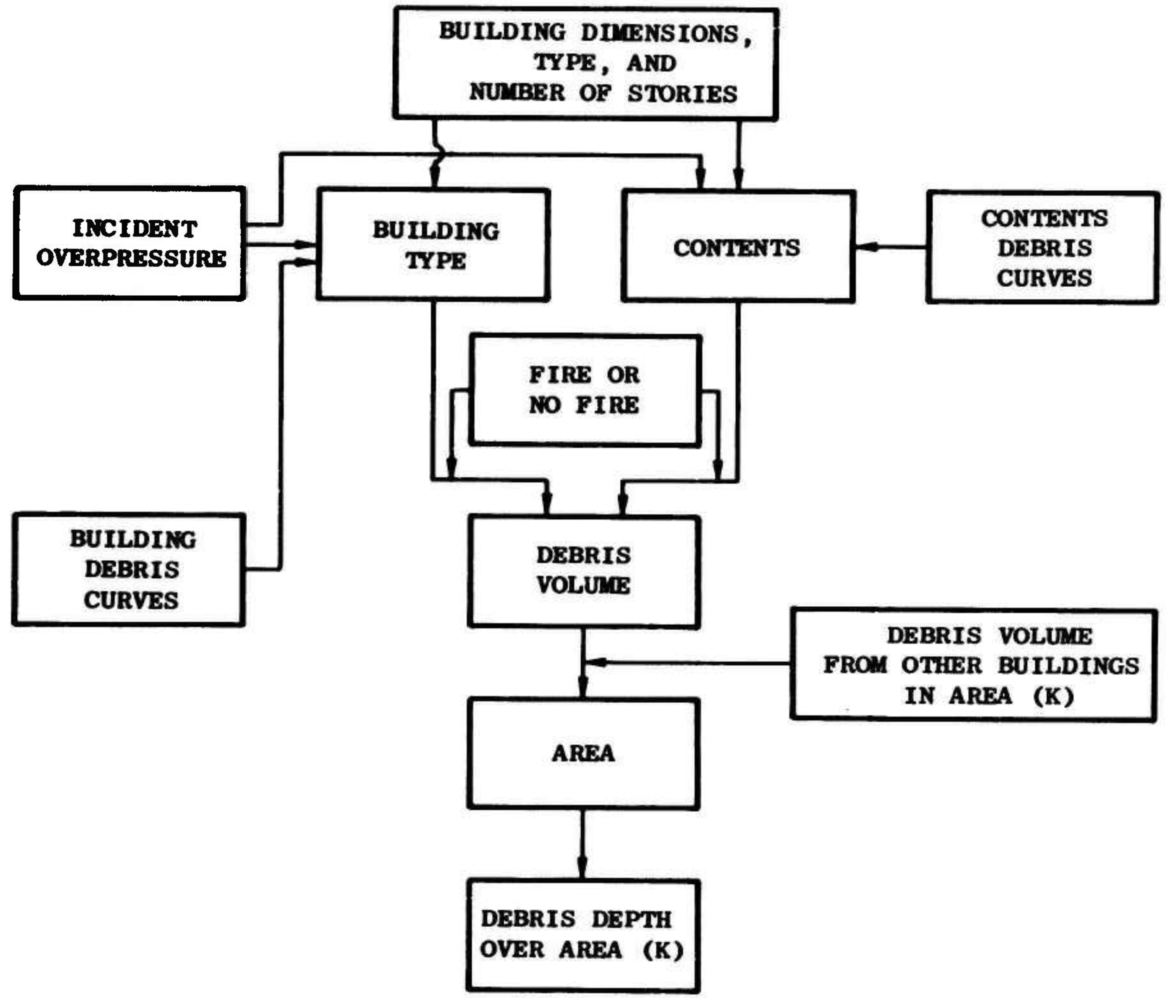


Fig. 2. Flow Chart of Computer Program to Calculate Debris Depths

```
C     URS CODE TO CALCULATE DEBRIS DEPTH
       DIMENSION  X(10,18,21),XX(18), XXX(18), JJ(30), XPP(30,10),
      XUL(30,10), UW(30,10), UH(30,10), PFAC1(21),    PFAC2(21),
      XL1(30,10), NN(30,10) ,MM(30,10) ,L2(30,10) ,UA(30) ,JJ1(30,10)
    1 FORMAT(31H  NO.     AREA    DEBRIS DEPTH )
    2 FORMAT (/  I4 ,  F11.4 , F15.5 )
      PFAC1(1)= .063
      PFAC1(2)= .12
      PFAC1(3)= .12
      PFAC1(4)= .002
      PFAC1(5)= .006
      PFAC1(6)= .002
      PFAC1(7)= .006
      PFAC1(8)= .002
      PFAC1(9)= .006
      PFAC1(10)=.06
      PFAC1(11)=.11
      PFAC1(12)=.07
      PFAC1(13)=.12
      PFAC1(14)=.063
      PFAC1(15)=.1
      PFAC1(16)=.07
      PFAC1(17)=.11
      PFAC1(18)=.07
      PFAC1(19)=.075
      PFAC1(20)=.037
      PFAC1(21)=.05
    4 FORMAT (3F5.1)
    5 FORMAT (10F5.1)
    6 FORMAT (I3)
    8 FORMAT (4F5.1,4I3)
    9 FORMAT ( F5.1,I3)
      READ (5,5),(((X(L,M,N),L=1,10),M=1,18),N=1,21)
      READ (5,4), ((XX(LL),XXX(LL),YYY(LL)),LL=1,21)
      READ (5,6),KK
      DO 20,K1=1,KK
      READ (5,9), UA(K1),JJ(K1)
      WRITE (6,9) ,UA(K1),JJ(K1)
      DO 20,J1=1,JJ(K1)
      READ (5,6),JJ1(J1,K1)
      WRITE(6,6))JJ1(J1,K1)
      READ (5,8),XPP(J1,K1),UL(J1,K1),UW(J1,K1),UH(J1,K1),
     XNN(J1,K1) ,MM(J1,K1) ,L1(J1,K1) ,L2(J1,K1)
      WRITE(5,8),XPP(J1,K1),UL(J1,K1),UW(J1,K1),UH(J1,K1),
     XNN(J1,K1) ,MM(J1,K1) ,L1(J1,K1) ,L2(J1,K1)
   20 CONTINUE
      IF(MM) 50,311,51
```

Fig. 3. Listing of Computer Program to Calculate Debris Depths

```
   50 PFAC2(1)=.625
      PFAC2(2)=.25
      PFAC2(3)=.75
      PFAC2(4)=.55
      PFAC2(5)=.09
      PFAC2(6)=.375
      PFAC2(7)=.625
      PFAC2(8)=.75
      PFAC2(9)=1.8
      PFAC2(10)=.55
      PFAC2(11)=1.2
      PFAC2(12)=.9
      PFAC2(13)=1.7
      PFAC2(14)=1.6
      PFAC2(15)=6.
      PFAC2(16)=2.
      PFAC2(17)=2.7
      PFAC2(18)=.6
   51 PFAC2(1)=.02
      PFAC2(2)=.007
      PFAC2(3)=.30
      PFAC2(4)=.2
      PFAC2(5)=.003
      PFAC2(6)=.03
      PFAC2(7)=.013
      PFAC2(8)=.027
      PFAC2(9)=.07
      PFAC2(10)=.20
      PFAC2(11)=.10
      PFAC2(12)=.20
      PFAC2(13)=.13
      PFAC2(14)=.02
      PFAC2(15)=.3
      PFAC2(16)=.1
      PFAC2(17)=.12
      PFAC2(18)=.02
C     K LOOP IS AREA LOOP --- J LOOP IS BUILDING LOOP
      WRITE OUTPUT TAPE 6, 1
      DO 311, K=1,KK
      VD=0.
      VFUR=0.
      DO 310, J=1,JJ
      XP=XPP(J,K)
      L11=L1(J,K)
      L22=L2(J,K)
      N=JJ1(J,K)
      M=L2(J,K)
      IF(XP-XX(L11))139,139,140
```

Fig. 3 (cont.)

```
  130 PFUR=0.
      GO TO 150
  140 IF(XP-XXX(L11))145,142,142
  142 PFUR=1.0
  141 GO TO 150
  145 PFUR=(XP-XX(L11))*YYY(L11)/(XXX(L11)-XX(L11))
  146 VFUR=PFUR*(UL*UW*NN(J))*PFAC2(L11)
      GO TO 150
C     THE FURNISHINGS VOLUME  DEBRIS CONTRIBUTION  IS VFUR
C     THE BUILDING STRUCTURE  DEBRIS CONTRIBUTION  IS VD
  150 IF (XP-X(4,M,N)) 160,160,165
  160 IF (XP-X(2,M,N)) 170,170,175
  165 IF (XP-X(6,M,N)) 250,260,260
  170 IF (XP-X(1,M,N)) 180,180,190
  175 IF (XP-X(3,M,N)) 200,200,210
  180 XS=0.
      XB=X(1,M,N)
      YB=0.
      YS=0.
      GO TO 300
  190 XS=X(1,M,N)
      XB=X(2,M,N)
      YS=0.
      YB=X(8,M,N)
      GO TO 300
  200 XS=X(2,M,N)
      XB=X(8,M,N)
      YS=X(8,M,N)
      YB=X(8,M,N)
      GO TO 300
  210 XS=X(3,M,N)
      XB=X(4,M,N)
      YS=X(8,L,M)
      YB=X(9,L,M)
      GO TO 300
  250 IF (XP-X(5,M,N))270,270,280
  260 XS=X(6,L,M)
      XB=X(7,L,M)
      YS=X(10,L,M)
      YB=X(10,L,M)
      GO TO 300
  270 XS=X(4,L,M)
      XB=X(5,L,M)
      YS=X(9,L,M)
      YB=X(9,L,M)
      GO TO 300
```

Fig. 3 (cont.)

```
  28C XS=X(5,L,M)
      XB=X(6,L,M)
      YS=X(9,L,M)
      YB=X(10,L,M)
      GO TO 300
  300 YS=YS+(YB-YS)*(XP-XS)/((XB-XS)*100.
C     SUM VOLUMES
      VD= UL(J,K)*UW(J,K)*UH(J,K)*PFAC1(L22)*VD+VFUR
  310 CONTINUE
C     CALCULATE DEPTH OF DEBRIS FOR  AREA UA(5)
      DEP=VD/UA(K)
      WRITE (6,2) , K,UA(K), DEP
  311 CONTINUE
      END
```

Fig. 3 (cont.)

Section 5
MULTIYIELD DEBRIS CHARTS

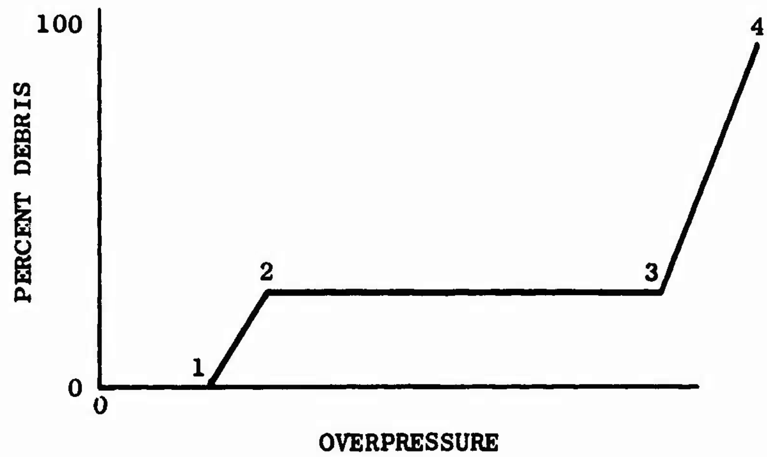
GENERAL

Prior work in debris production and debris distribution generated debris charts for various building types for 20-kt and 20-Mt weapon sizes. The present work has generated charts for the additional weapons sizes of 100 kt, 500 kt, 1 Mt, 10 Mt, and 50 Mt. The structural types for which the new charts have been constructed are:

- Reinforced concrete shearwall
  1. with light interior panels
  2. with masonry interior panels
- Multistory steel or reinforced concrete frame with earthquake design
  1. with light exterior panels
  2. with masonry exterior panels
- Multistory steel or reinforced concrete frame without earthquake design
  1. with light exterior panels
  2. with masonry exterior panels
- Light reinforced concrete shearwall - single story
  1. reinforced concrete roof
     - light interior panels
     - masonry interior panels
  2. mill-type roof
     - light interior panels
     - masonry interior panels

The complete set of debris charts for all structure types and for all weapon yields is presented in Appendix B.

A simplified example of a debris chart is shown below:



Points 1 and 2 are the initiation and completion, respectively, of failure of frangible (diffraction-phase-sensitive) elements such as panels, doors, suspended ceilings, etc., and the overpressure vs. percent debris location of these points is relatively independent of weapon yield.

This task concerned itself with the location of points 3 and 4, which do depend on weapon yield.

The plateau from point 2 to point 3 is caused by the difference in overpressure between the final failure of the frangible parts of the building, and the start of failure of the drag-sensitive or ductile structure of the building. The load-carrying portion of most buildings is composed of relatively ductile materials and arranged structurally so that failure occurs only after some yielding of the load-carrying members.

The location of points 3 and 4 is determined by the failure characteristics of the main structural system, point 3 representing the overpressure at which elements of the main structural system would begin to fail (generally similar to overpressures for severe damage or threshold of collapse) and point 4 representing the overpressure for complete destruction (100 percent debris). Again, the percent debris range between points 3 and 4 indicates the relative volume of material in the main structural system.

For drag-sensitive structures, such as those on which the simplified example above is based, values of incident overpressures at points 3 and 4 are dependent on: the dynamic response characteristics of the structure to the start of failure; the structure's ability to absorb additional energy at various stages of failure; and, of course, the duration of the associated dynamic pressure pulse. As a consequence, the location of debris chart terminal limbs is weapon-yield dependent.

For each structure type, debris charts covering a large range of weapon yields are relatively easy to construct, once the values of points 3 and 4 are known. Generally, only the terminal limb of a debris chart is yield sensitive, and therefore a multiplicity of yields can be covered by constructing a family of terminal limbs imposed on the non-yield-sensitive portions.

These charts were constructed by first plotting a pair of isodamage curves, one of which defines the onset of structural collapse and the other which defines complete collapse. These curves are plotted as a function of incident overpressure vs. weapon yield, thereby enabling the terminal limb of the debris chart to be constructed.

MULTISTORY STEEL AND REINFORCED CONCRETE FRAME BUILDINGS

The collapse of a multistory building due to a nuclear blast is a process which depends on many factors. The following is a partial listing:

1. Building type - steel frame, reinforced concrete frame
2. Building geometry - number of stories, plan dimensions
3. Mass of floors (after walls and internal partitions have been blown away)
4. Stiffness and yield levels of the framing elements
5. Shape and duration of the blast pulse

The response of multistory buildings to blast loadings can be calculated most accurately by envisioning the system as a nonconservative, nonlinear, multispring, multimass, time-varying forcing function dynamics problem. Such a problem can be solved adequately only by resorting to a computer solution.

In 1963 and 1964, T. Y. Lin & Associates undertook (under the sponsorship of OCD) the writing of a computer code which would describe the dynamic reactions of a high-rise building when subjected to blast loading. This code takes into account time dependency of loading, plastic resistance of the structural members, and varying loads on the different floors. It accounts for structural damping and calculates deflections, forces, and ductility ratios in the structural members for a multimass system. It describes the multimass-nonlinear spring-mass system (the building) as well as any computer code or computational scheme currently available.*

The computer code will not tell whether a building has collapsed when hit with a given blast. It will tell how much ductility the structural members have suffered, how much maximum axial force each column has experienced, and what the maximum floor deflections are. The most enlightening quantity is the ductility ratio which is defined as the ratio of the plastic rotation to the elastic rotation capacity of a structural element. The ductility ratio is an indication of the distortion of the frame. If the ductility ratio is plotted vs. peak overpressure, it is found to increase with increasing steepness as overpressure goes up, so that the structure's collapse may be arbitrarily set at some point where this curve is so steep that a slight increase in overpressure causes a greatly disproportionate increase in ductility ratio.

THE DYNAMIC MODEL

The "typical" 10-story office building (Fig. 4) was designed by Dr. H. Hahne of the University of Santa Clara in both steel framing and in reinforced concrete framing. Both wind loadings and earthquake loadings were considered.

These model buildings were analyzed by URS for the effects of blast in both longitudinal and transverse directions (Fig. 5). The T. Y. Lin - OCD code (Ref. 8) to analyze the dynamic response of high-rise buildings to nuclear blast loadings (elasto-plastic) was used. Standard sea level atmospheric

* Two of the codes considered were the Sandia "Shock" code and the Jet Propulsion Laboratories Stiffness Matrix Structural Analysis code.

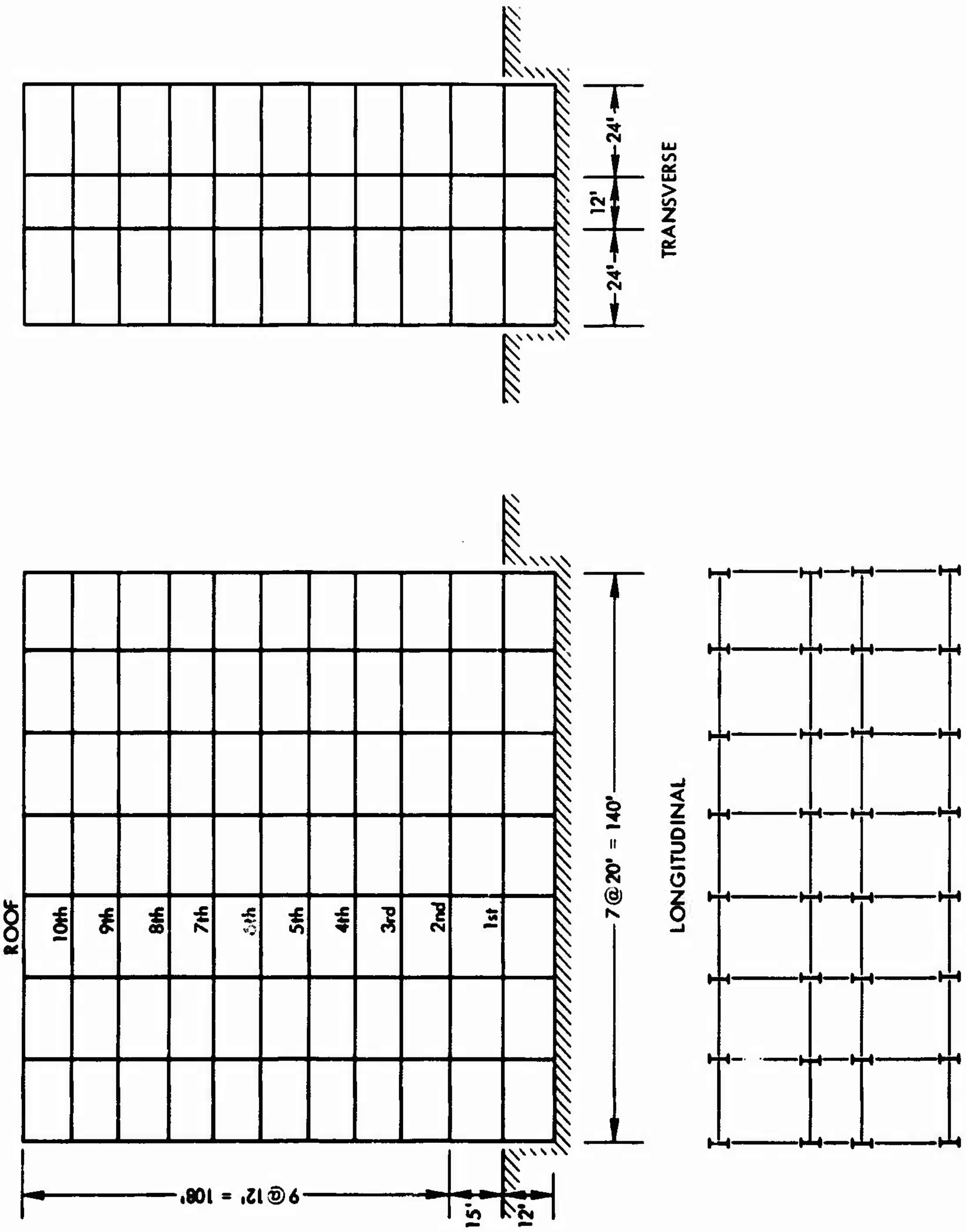
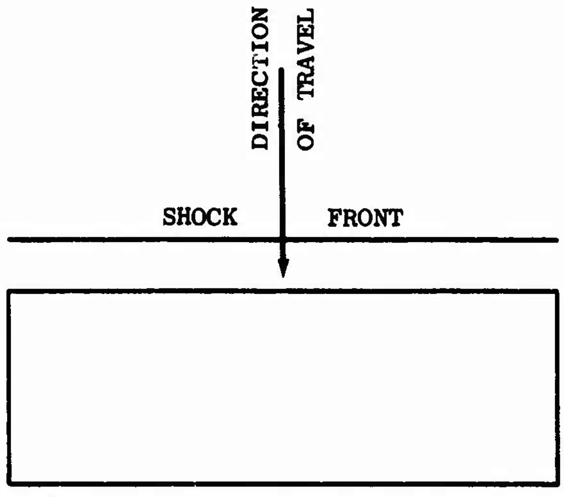
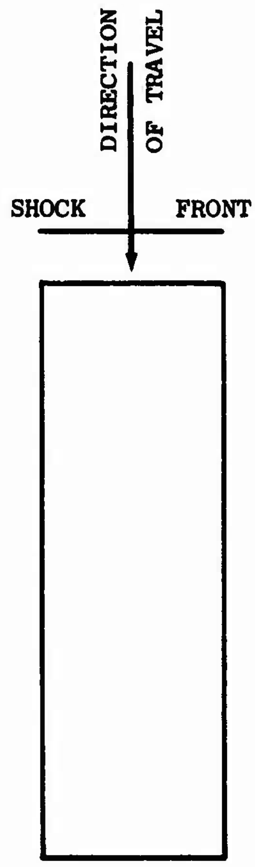


Fig. 4. "Typical" Frame Office Building



TRANSVERSE ORIENTATION



LONGITUDINAL ORIENTATION

Fig. 5. Orientation of Building with Respect to Blast Wave

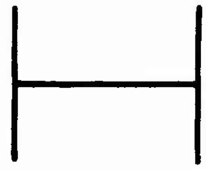
conditions and zero HOB were assumed. The walls were assumed to blow out within 0.010 sec for both the front and back walls. The interior partitions were assumed to contribute no loading to the frame structure of the buildings. All materials were assumed to have been blown out of the building, with the floor slab and the frame system remaining. The assumed 0.010 second wall failure time is felt to be valid for frangible walls (such as light metal panels).* The assumption that the interior partitions contribute no loading to the frame is justified since most partitions have no structural function serving only to delineate office space. The third assumption that all of the contents are ejected from the building is open to some question, but it is likely that, at the overpressures and durations considered in this study, most of the contents will be ejected.

With the structure of the building virtually swept bare by the early part of the blast wave, the major contributor to the frame failure is the drag portion of the blast wave. Since the following analysis was performed for face-on blast waves, the steel and reinforced concrete structural members could be oriented in one of three ways as shown on the next page:

---

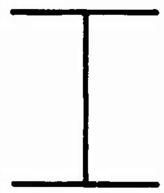
* A brick curtain wall would not be considered frangible in this sense. It will take longer than 0.010 seconds (depending on the overpressure) for a brick wall to be blown out. Experiments are now being performed in the URS shock tunnel which will help to determine the time to failure of brick walls, and the load transmitted to the structures' frame before failure. It is possible that these experiments will result in new debris charts for steel or reinforced concrete frame buildings with masonry curtain walls, showing them to collapse at a different overpressure than these types of buildings with light panel walls.

TRANSVERSE
DIRECTION OF FLOW
→
(steel member)



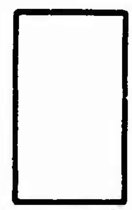
$(C_D = 1.5)$

LONGITUDINAL
DIRECTION OF FLOW
→
(steel member)



$(C_D = 2.05)$

DIRECTION OF FLOW
→
(concrete member)



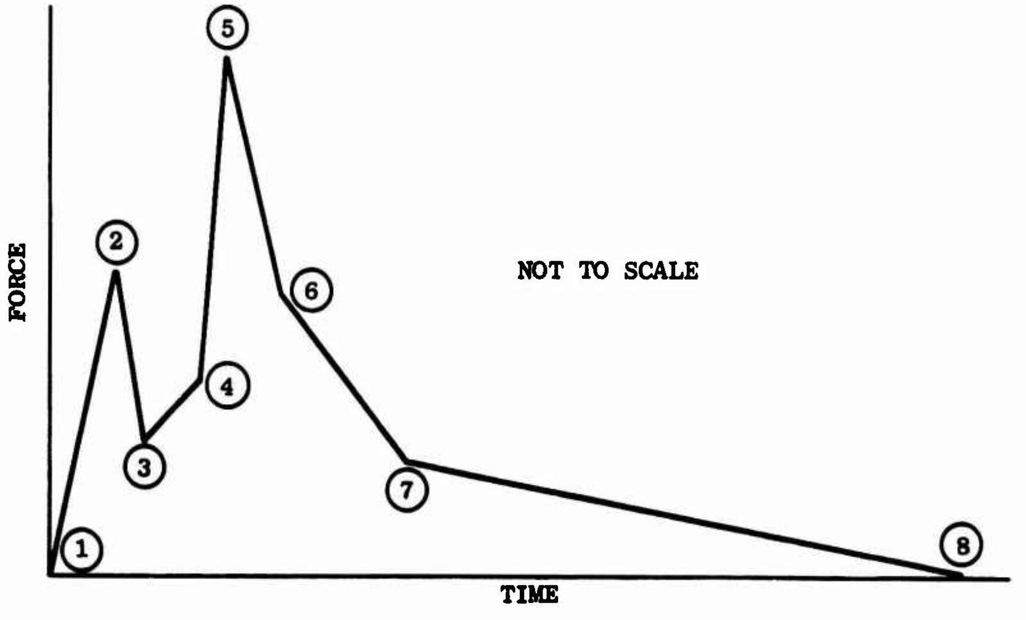
$(C_D = 1.5)$

where C_D is the drag coefficient taken from Ref. 9.

For purposes of this analysis, the greater distance from ground zero to the back face of the building than to the front face was ignored and no attenuation of the dynamic pressure ascribable to this circumstance was made. The shielding of some structural members by others standing ahead of them in the path of the blast wave was similarly ignored. This is permissible because these members are sufficiently far apart to allow virtually complete dynamic pressure recovery. Thus drag loading was computed by simply summing the drag areas of the columns and girders multiplied by their applicable drag coefficients (C_D).

The load-time curve shown below is the result of both phases (diffraction and drag) interacting with the panels and structural members of the building. The first loading spike (points 1 to 3) is caused by the reflected pressure acting on the front face of the building. The blast wave sweeps through the

building, causing a rising drag force on the frame (points 3 to 4). The blast wave strikes the back of the rear face of the building, and a second spike is caused by the reflected pressure (points 4 to 6). Point 5 is higher than 2 because of the additional drag forces on the structural frame members between the front and the rear face. The exponential decay (points 6 to 8) of the drag portion of the curves was approximated by two straight-line segments.

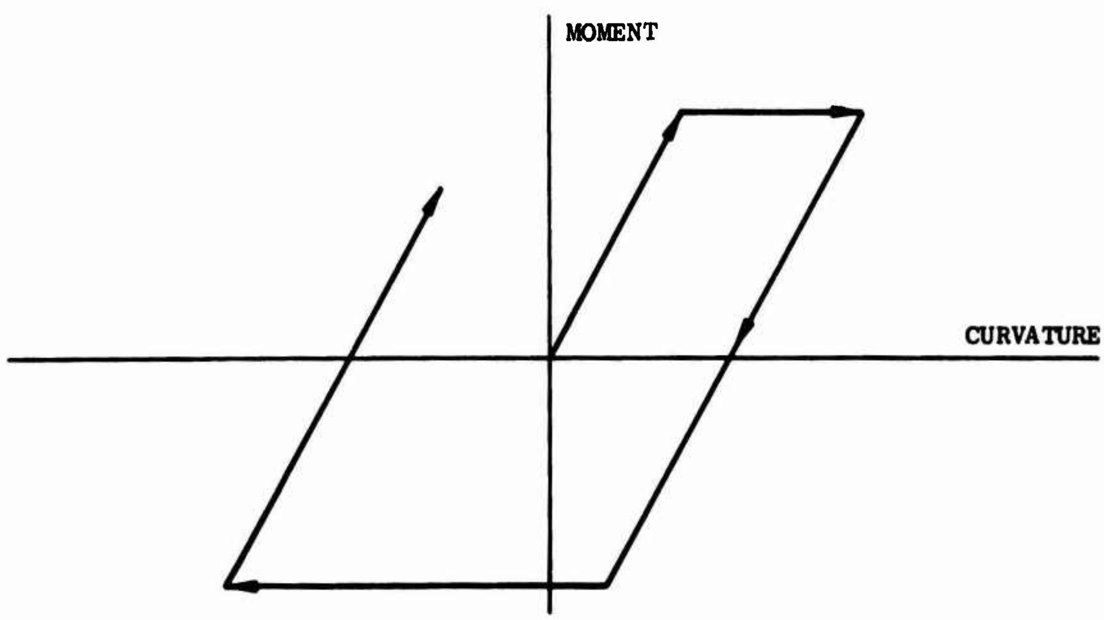


As an example, the load-time points for the foregoing curve are listed below for the steel building in the transverse direction (10 Mt, 10 psi overpressure).

The mass properties for a given story were computed simply by summing the masses of the structural members and floor slab. All other masses were assumed to have been blown away in the very early part of the blast incursion.

POINT	LOAD (kips)	TIME (sec)
1	0.0	0.000
2	602.0	0.005
3	20.0	0.010
4	76.0	0.040
5	696.0	0.045
6	94.5	0.050
7	28.4	2.25
8	0.0	7.5

Girders and columns are assumed to exhibit the following elastoplastic characteristics:



The above diagram depicts the manner in which the rotation of the member elastically increases as the moment increases, up to the point where the member becomes plastic, at which point the member continues to rotate with no corresponding increase on applied moment. As the moment is reduced the curvature decreases, but does not return to zero at zero moment as some permanent curvature is retained.

This is a valid idealization for wide flange structural steel beams, and for doubly-reinforced concrete beams. (Refs. 10 and 11.)

Computer runs were made for various overpressures at 20-kt, 100-kt, 1-Mt and 10-Mt yields. A summary of these ductility ratio values is listed in Table 3 and plotted in Fig. 6. Final failure was assumed to have occurred in the building when the ductility ratio (D.R.) (the ratio of the plastic rotation at yield stress) of the bottom set of columns reached 20.0 for the steel members and 50.0 for the reinforced concrete members. It should be noted that girders in the center bay had ductility ratios higher than those for the columns, but this would not have caused collapse of the structure. It should also be noted that while ductility ratios of 20.0 and 50.0 are arbitrary, increasing them would make little difference in the failing overpressures because of the steepness of the ductility-overpressure curves in the region of interest.

Consideration of Fig. 5 indicates that one factor not previously given prominent consideration could play quite a part in building collapse. If a steel frame has a rectangular plan with the long dimension appreciably greater than the short dimension, then it could be significantly more vulnerable when hit by a nuclear blast wave in the long (longitudinal) direction than when hit on the larger face (transverse direction). The reason for this is the extra drag imposed on the frame by the blast wind blowing over the larger number of girders and columns in the long direction. This condition can be aggravated if the columns are oriented so that their webs are facing the blast. A blast wave striking the building in some oblique direction would cause a different loading, and there is evidence to show that the loading on a frame structure will be greatest at some angle other than perpendicular to one of the axes. However, not enough is known to make an accurate determination of this difference, and for a very open structure, such as a frame building after the walls are blown out, the difference will not be great (Ref. 12).

Another factor that has not been considered here is the likelihood of overturning. It is quite possible that, given the proper foundation conditions, a structure will overturn at an overpressure less than that required for severe

Table 3

SUMMARY OF DUCTILITY RATIOS

YIELD	OVERPRESSURE (psi)	MAXIMUM GIRDER D.R.	MAXIMUM COLUMN D.R.
STEEL BUILDING			
Transverse Direction			
20 kt	15	27.28	10.2
20 kt	20	49.86	22.1
20 kt	25	75.1	38.6
100 kt	10	17.4	7.6
100 kt	15	41.6	19.1
100 kt	20	76.6	38.4
1 Mt	5	3.1	<1
1 Mt	10	32.4	16.0
1 Mt	15	75.4	39.7
10 Mt	5	4.0	<1
10 Mt	7.5	20.8	10.6
10 Mt	10	53.8	27.7
Longitudinal Direction			
20 kt	10	16.6 (5)	11.99
20 kt	15	43.6 (5)	34.1
20 kt	20	68 (2)	55.73
100 kt	7.5	12.99(5)	10.51
100 kt	10	29.1 (4)	23.7
100 kt	15	78.3 (2)	63.8
1 Mt	2.5	<1	<1
1 Mt	5	6.8 (3)	5.5
1 Mt	10	60.7 (2)	48.8
10 Mt	2.5	<1	<1
10 Mt	5	5.2	10.4
10 Mt	7.5	11.8	40.9

Table 3 (cont.)

YIELD	OVERPRESSURE (psi)	MAXIMUM GIRDER D.R.	MAXIMUM COLUMN D.R.
CONCRETE BUILDING			
Transverse Direction			
20 kt	10	22.9	35.79
20 kt	15	48.03	70.19
20 kt	20	83.01	126.1
100 kt	7.5	17.45	29.50
100 kt	10	36.85	60.37
100 kt	15	76.40	118.98
1 Mt	5	7.7	15.57
1 Mt	7.5	29.05	51.98
1 Mt	10	63.17	102.12
10 Mt	5	11.56	21.45
10 Mt	7.5	50.29	83.24
10 Mt	10	105.19	167.3
Longitudinal Direction			
20 kt	5	1.74	3.32
20 kt	10	11.02	30.87
20 kt	20	45.33	116.64
100 kt	5	2.16	7.45
100 kt	10	20.5	58.16
100 kt	15	56.2	139.6
1 Mt	2.5	<1	<1
1 Mt	5	4.34	16.75
1 Mt	10	39.5	104.9
10 Mt	2.5	<1	1.16
10 Mt	5	7.85	27.3
10 Mt	7.5	32.8	91.5

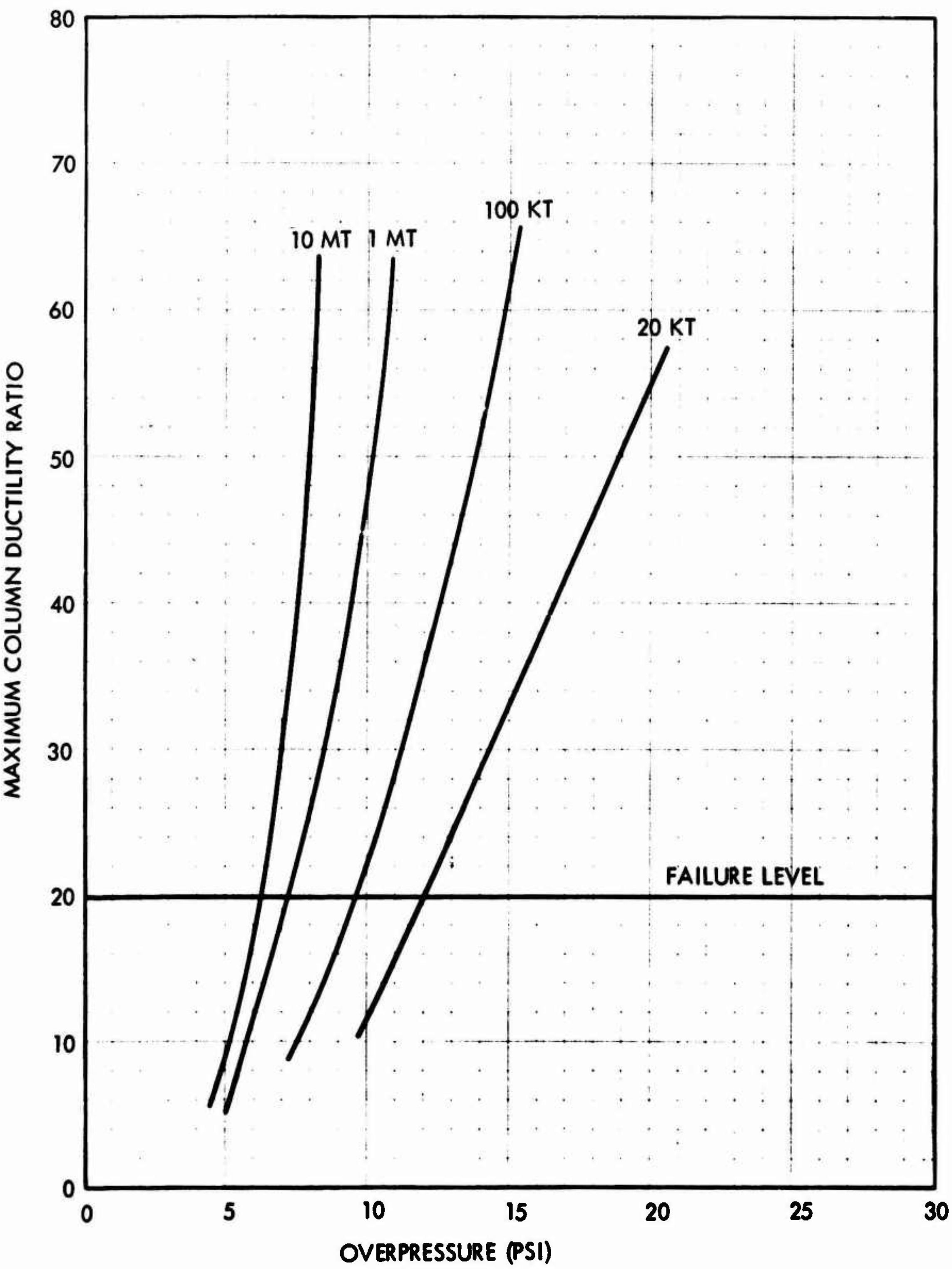


Fig. 6a. Maximum Column Ductility Ratio vs Incident Overpressure — Steel Frame Structure, Longitudinal Direction

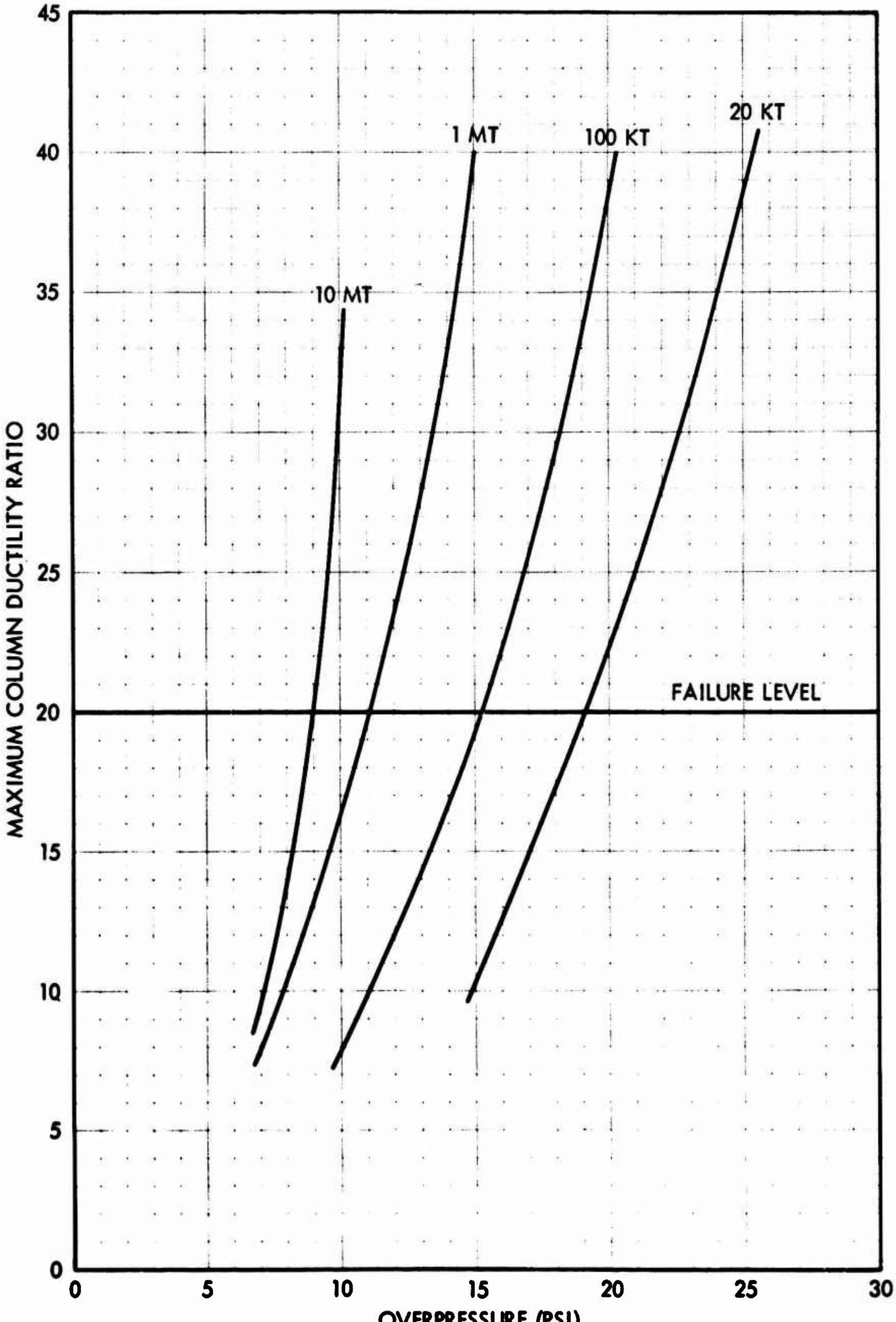


Fig. 6b. Maximum Column Ductility Ratio vs Incident Overpressure — Steel Frame Structure, Transverse Direction

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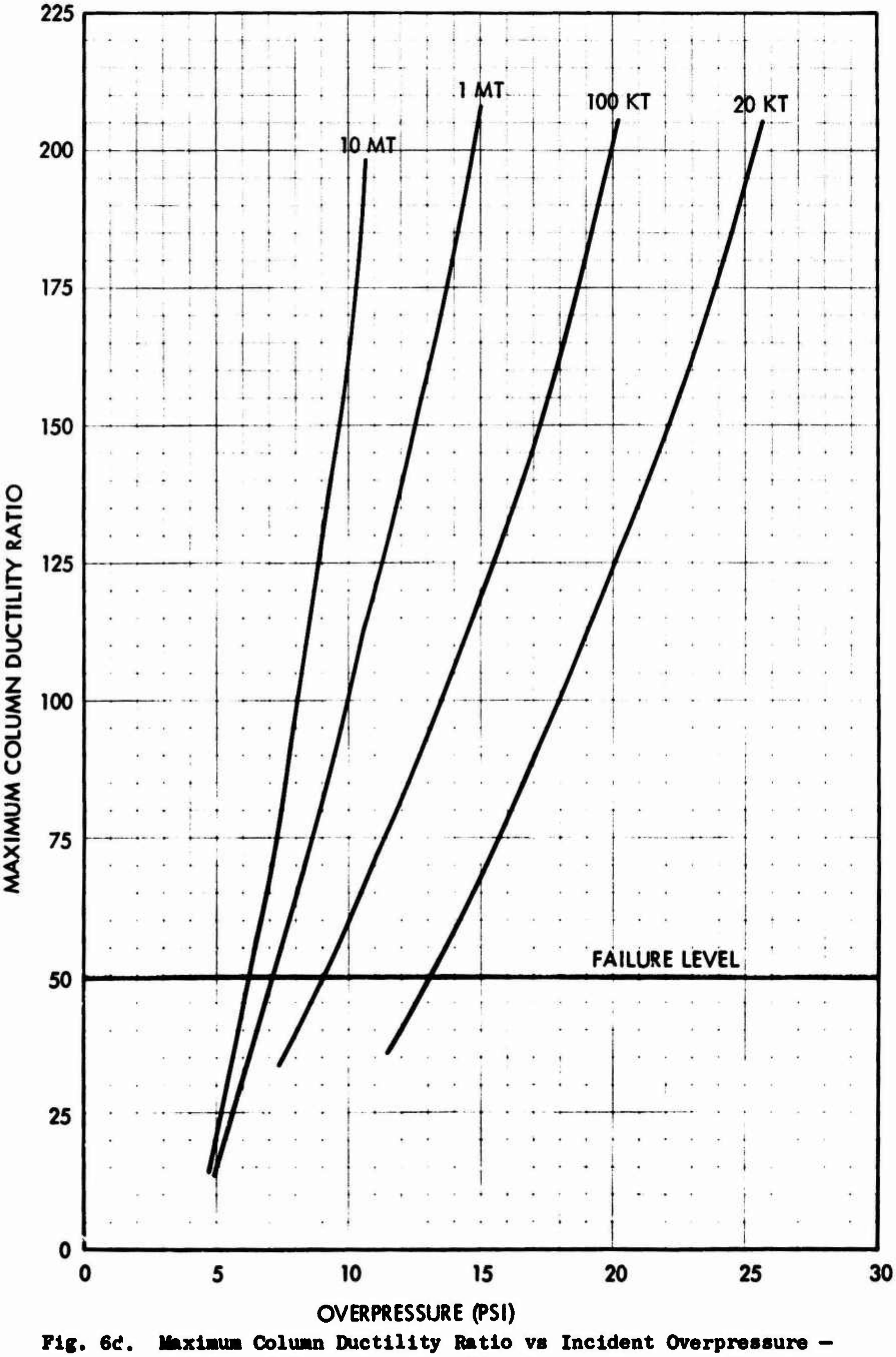


Fig. 6c. Maximum Column Ductility Ratio vs Incident Overpressure — Reinforced Concrete Frame Structure, Transverse Direction

damage (Ref. 4). Again, the orientation of the building could be critical in regard to overturning. A long, narrow building would be quite vulnerable to overturning due to a blast wave striking it on its long face, whereas overturning would not be a problem if the blast was normal to its short face.

STEEL FRAME EARTHQUAKE DESIGN

For a steel frame building, the differences in behavior failure of a given failure overpressure deriving from differences between earthquake and wind design would be virtually indescernible. As mentioned before, the "typical" steel frame building analyzed was critical for earthquake in the long direction and critical for wind in the short direction. For blast loading, however, it was stronger in the short (wind design) direction than in the long (earthquake design) direction. Failing overpressure differences due to geometry would be much larger than such differences due to different design criteria.

CONCRETE FRAME EARTHQUAKE DESIGN

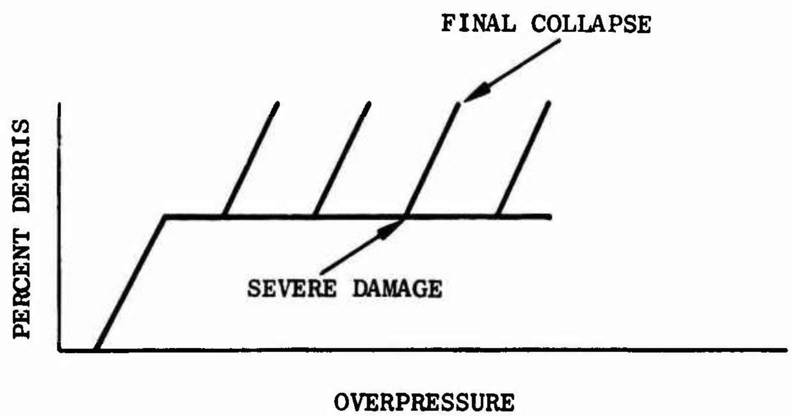
The concrete frame building used was critical for earthquake in both the long and the short directions because of its greater mass.* It exhibited almost no directional sensitivity.

TERMINAL LIMB FOR MULTIYIELD CURVES

The two points defining the terminal limb of the debris curves were investigated for various yields. The two points are the severe damage point and the final collapse point as shown on the following page.

---

* Earthquake loadings are a function of the mass of a building, while wind loadings are a function of the area subjected to drag forces.



Previously values for severe damage were taken from TM 23-200 and final collapse points were calculated by means of the methods outlined in Refs. 11, 13 and 14. The values for both points were changed in the manner described below.

The severe damage point for various yields on the debris curves was calculated by averaging overpressure values from TM 23-200 and from the computer runs. The averaging process is an attempt to get around the problem of placing upper and lower bounds on the debris curves. In actuality, the debris curves are probabilistic, and there should be a distribution shown on both sides of the curves. Data and methods leading to the determination of these bounds are presently being developed.

The overpressure difference between severe damage and final collapse is taken as the overpressure difference between failure of the girders and failure of the columns (averaged for all building types). In general, during a blast incursion the girders of the middle floors undergo plasticity first (reach a ductility ratio of 1.0 first). The columns of the first floor are the first set of columns to exhibit plasticity, and when these reach a failing ductility, the building has reached its collapse overpressure. By knowing these two values for various weapon yields, the terminal limb of the debris production curve was constructed. Fig. 7 indicates the values used for these two points for frame buildings without earthquake design, and Fig. 8 is for frame buildings with earthquake design.

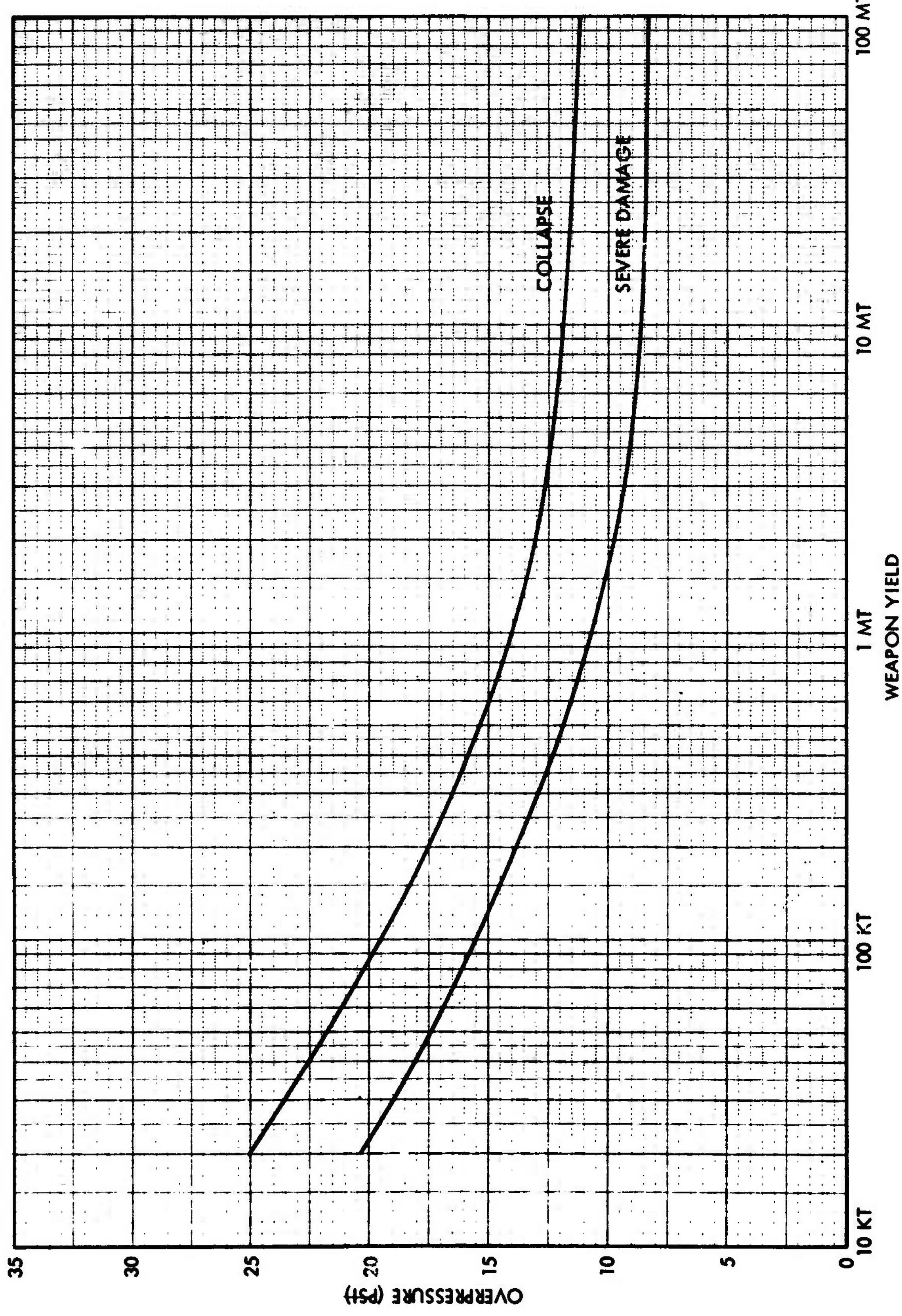


Fig. 7. Isodamage Curves – Steel or Reinforced Concrete Frame Building Without Earthquake Design

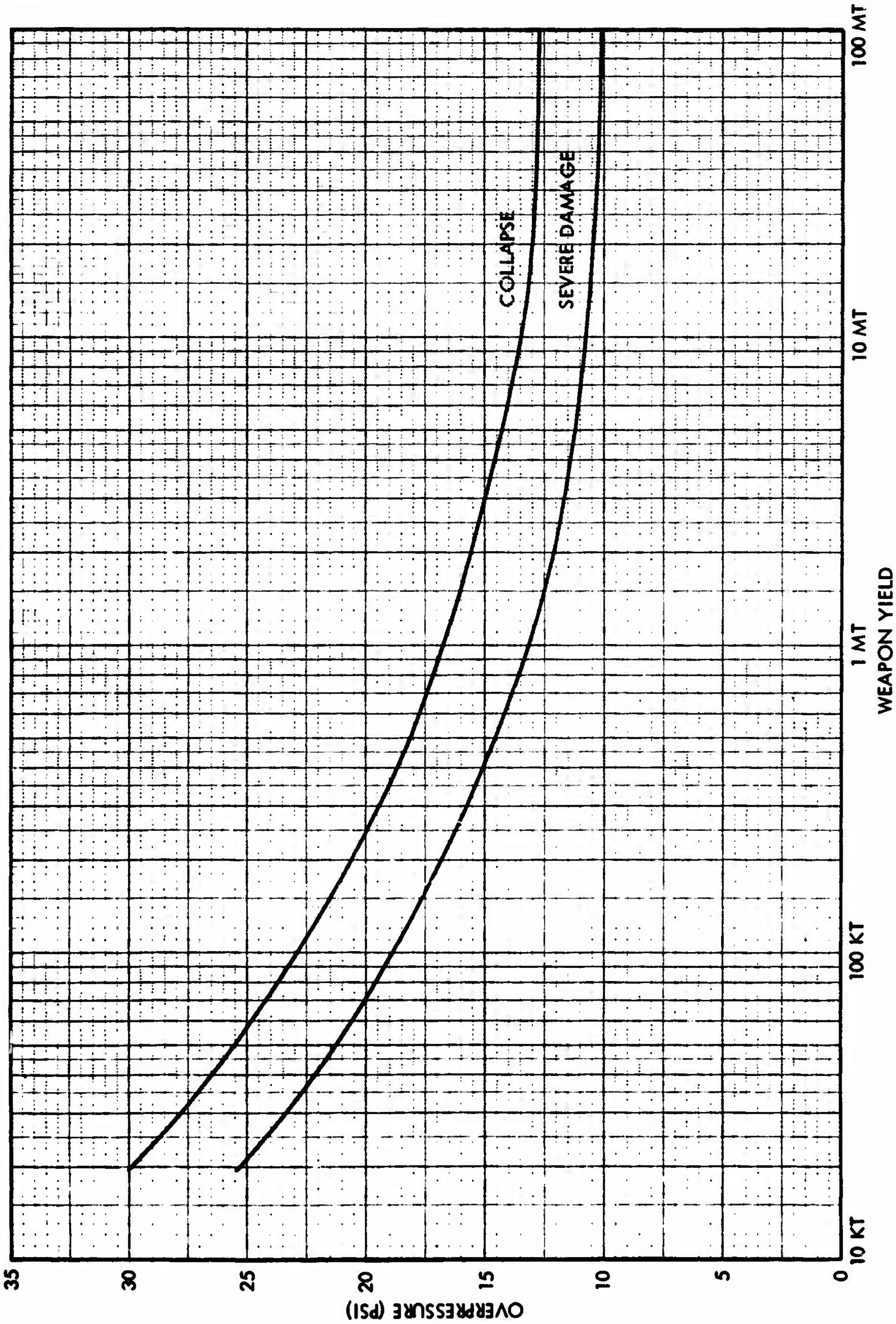
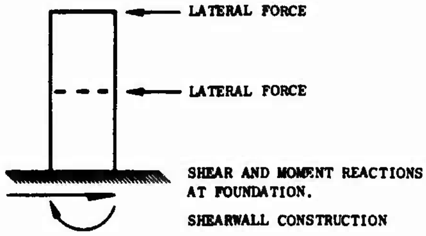
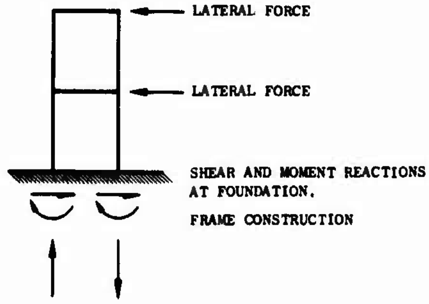


Fig. 8. Isodamage Curves - Steel or Reinforced Concrete Frame Building With Earthquake Lesign

REINFORCED CONCRETE SHEARWALL BUILDINGS

A shearwall structure is one that carries lateral loads generated by wind, earthquake, or blast to the foundation by shear without large concentrated moments acting on any members. A simplified shearwall structure is contrasted to a frame type structure below:





Lateral loads due to blast can be much greater on shearwall buildings because the blastward walls remain intact, thereby causing a greater diffraction loading. The drag loading, however, on a shearwall structure is not necessarily greater than the drag loading of a frame type building of equivalent geometry, because the loaded area of the frame (girders and columns) may be greater than the loaded area of the shearwalls.

The debris vs overpressure curves for heavy reinforced concrete shearwall buildings were originally derived from Hiroshima and Nagasaki information. The buildings were not very tall – an average height would be 2 to 3 stories – and were of very heavy construction. These are left as a category by themselves. No comparable construction exists in the U.S. in any quantity.

A new category for buildings of from 3 to 8 stories in height and of shearwall construction was formed. Information in TM 23-200 was used to draw the severe damage line of Fig. 9. This type of construction has a characteristically small ductility of between 3 and 7. Thus the change in overpressure from severe to ultimate damage is also small, and this change decreases only slightly as the yield increases (Fig. 9).

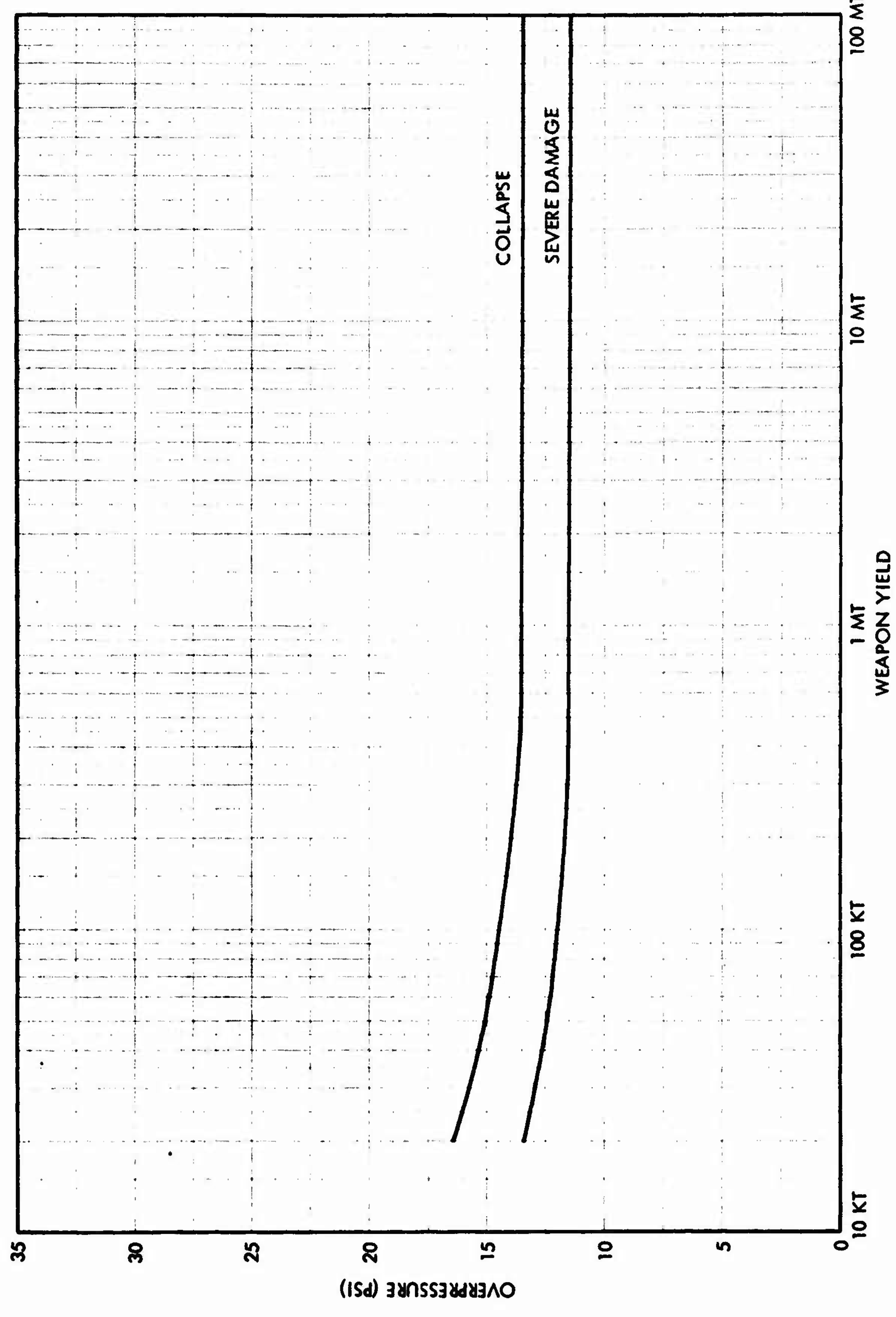


Fig. 9. Isodamage Curves — Multistory Reinforced Concrete Shearwall Building

Shearwall-type buildings can be either entirely of shearwall construction or partial shearwall construction. Quite often, a building is shearwall in one direction and concrete frame in the other direction; thus care must be used in applying these carts so that the chart is related to the orientation of the building.

LIGHT REINFORCED CONCRETE SHEARWALL - SINGLE STORY

No basic changes were made in these curves; however, they were extended to cover other yields.

Light reinforced concrete shearwall buildings are basically single-degree-of-freedom structures, usually 1 story high. These usually have small window openings, are rectangular in form, and as such are the structural type for which blast loading can be defined with the greatest confidence.

This type of structure is lightly framed, with most of the lateral loading transferred to the foundation through panel shear. Vertical loads acting on the roof are carried to ground by both the panels and the frame.

Like the heavy reinforced concrete shearwall buildings, the light reinforced concrete shearwall buildings exhibit almost no yield dependency, and like their heavier counterparts, their basic ductility is limited. The difference in overpressure from severe damage to ultimate damage (collapse) is 2.0 psi at 20 kt and 1.0 psi at 50 Mt. Figure 10 was drawn from debris charts contained in a previous report, URS 651-4 (Ref. 3).

REINFORCED MASONRY LOAD-BEARING WALL BUILDING

The curves for this category, included in previous URS reports concerning debris production, have been omitted from this report. It is felt that the curves represented a very massive type of construction that was not representative of, and therefore not applicable to, what would be considered U.S. construction practice. This category as found in the U.S. (mostly single story stores or schools) would behave similarly to the light reinforced concrete shearwall type of structure.

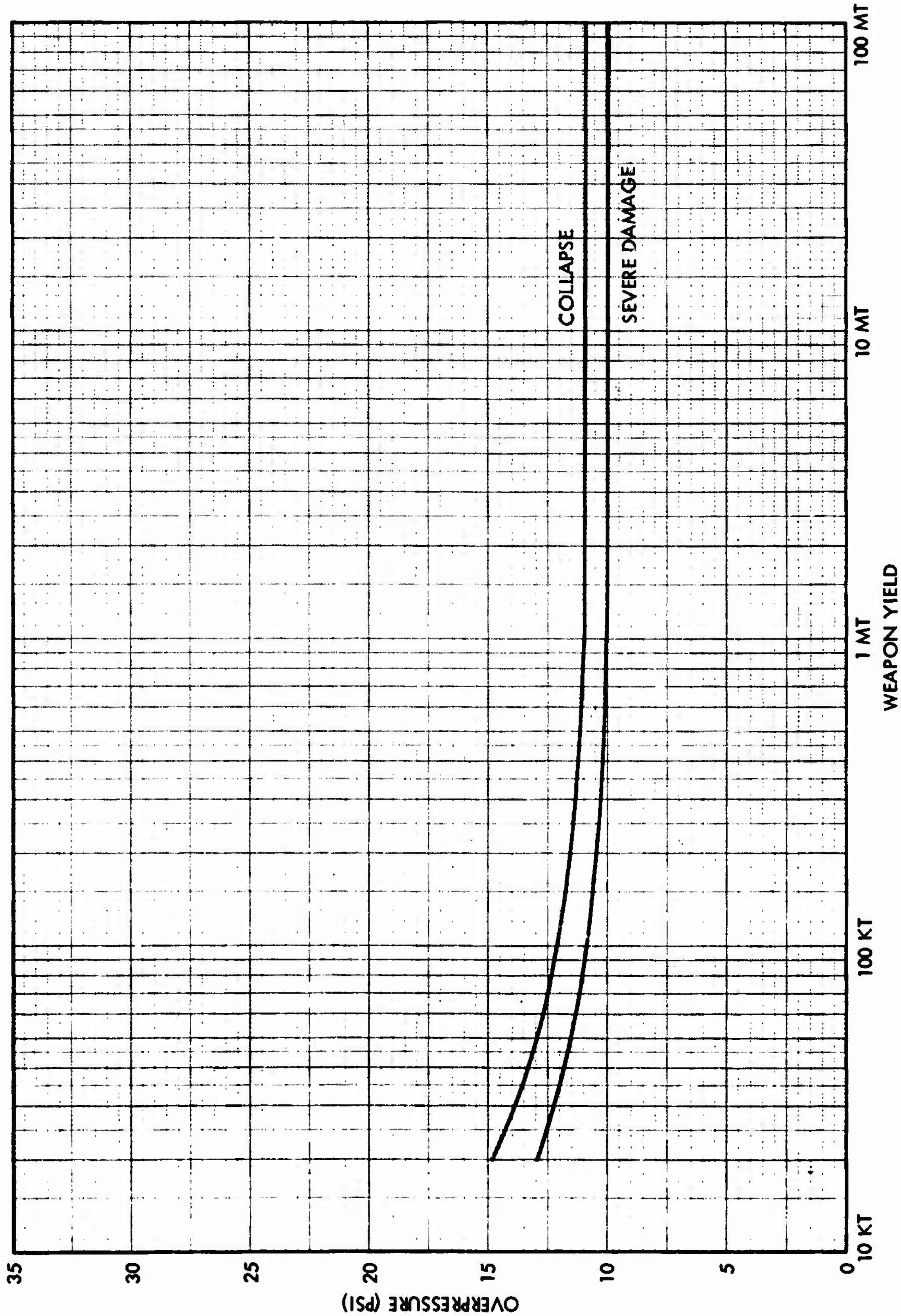


Fig. 10. Isodamage Curves — Light Reinforced Concrete Shearwall Building

COMPARISON OF RESULTS

One of the more interesting results of the computer study was the difference between the severe damage overpressures predicted by the T.Y. Lin — OCD code and those predicted in TM 23-200 (Ref. 5) and in ENW (Ref. 15). There was also a study done in 1957 by Namyet at MIT for the Air Force which supports the code results (Ref. 16). The first two references indicate much higher overpressures necessary for severe damage than the code and the MIT study do for some building categories. For a multi-story steel frame building without earthquake design, the results show good agreement. For a steel frame building with earthquake design the results differ by a factor of approximately 3. For a multi-story reinforced concrete frame building (either with or without earthquake design), the results again differ by a factor of 3. For OCD purposes, it is better to use the conservative results as predicted by the code, however, for accurate building damage predictions, the differences should be resolved.

Section 6
EXAMINATION OF WOOD FRAME BUILDINGS

GENERAL

The question of whether wood frame buildings produce debris at lower over-pressures for megton yields than for kiloton yields is one which has never been fully analyzed. Most weapon test data originated in tests with low-yield weapons.

In this task, pertinent data from nuclear weapons tests were examined to determine if the damage to this building type is dependent on weapon yield. Structural calculations were also performed to determine the yield-dependency of these types.

In order to determine whether the failure of wood frame structures can be correlated to yield, a structural model will be postulated and analyzed for the following:

1. Sensitivity of failure levels to overpressure loading
2. Sensitivity of failure levels to drag loading
3. Sensitivity of failure levels to weapon yield

To do this, the blast loading is separated into its diffraction component and its drag component. The structural model is analyzed for each component separately. The analysis indicates that wood frame structures as typified by the model have the following characteristics:

a. The critical load-carrying members (the wall studs) begin to fail due to the diffraction part of the blast loading at close to 1.2 psi

b. The stresses due to drag-induced loading are virtually yield-independent for overpressures of interest. These stresses depend almost solely on overpressure level

c. The beginning of stud failure is independent of yield and takes place at slightly over 1.2 psi

THE STRUCTURAL MODEL

The structural model to be analyzed is a frame structure, 8 ft high from floor to ceiling, with window openings spaced 3 ft apart (typical of frame residences). The existence of openings is very important to the structure because it allows the clearing or equalization of the overpressure. If there are no openings, the reflected overpressure would act for longer time and the structure would fail at a lower overpressure than if it had openings.

The basic load-carrying member for exterior wood frame walls is the 2 in. by 4 in. (rough dimension) stud. These are spaced approximately 16 in. center to center and are approximately 8 ft tall.

Rupture stresses for bending under static conditions are listed in Mark's Mechanical Engineers Handbook (Ref. 17) for softwoods, and these stresses vary from 8600 to 10,600 psi. Taking 9600 psi as an average rupture stress, a 2- by 4-in. stud would withstand an overpressure of 1.2 psi, as indicated by the following analysis.

Load Path for Frame Structure. Lateral loads (wind or blast) on a single-story frame structure are beamed to the ceiling and to the floor by the exterior wall studs. The loads are sheared to the side walls (assuming no load carrying interior walls) and then to ground. This loading sequence is shown in Fig. 11.

The weakest link in this chain or series of loading links is the first, the exterior wall stud. Studs are nailed to headers by either four-8-penny nails or three-16-penny nails, both top and bottom, per Uniform Building Code (Ref. 18). Modern Timber Engineering by Scoffield and O'Brian (Ref. 19) indicates that each joint has an average lateral resistance of 246 lb for four-8-penny nails and an average of 254 lb for three-16-penny nails. Taking the weaker joint, an allowable lateral pressure is calculated to be 0.32 psi.

The Uniform Building Code lists allowable bending stresses from 1200 psi to 2050 psi for light framing. Taking an average of 1625 psi in bending, the allowable pressure is calculated to be 0.31 psi. Mr. John Shope, Chief Engineer of the National Forest Products Association (in a private communication) indicated

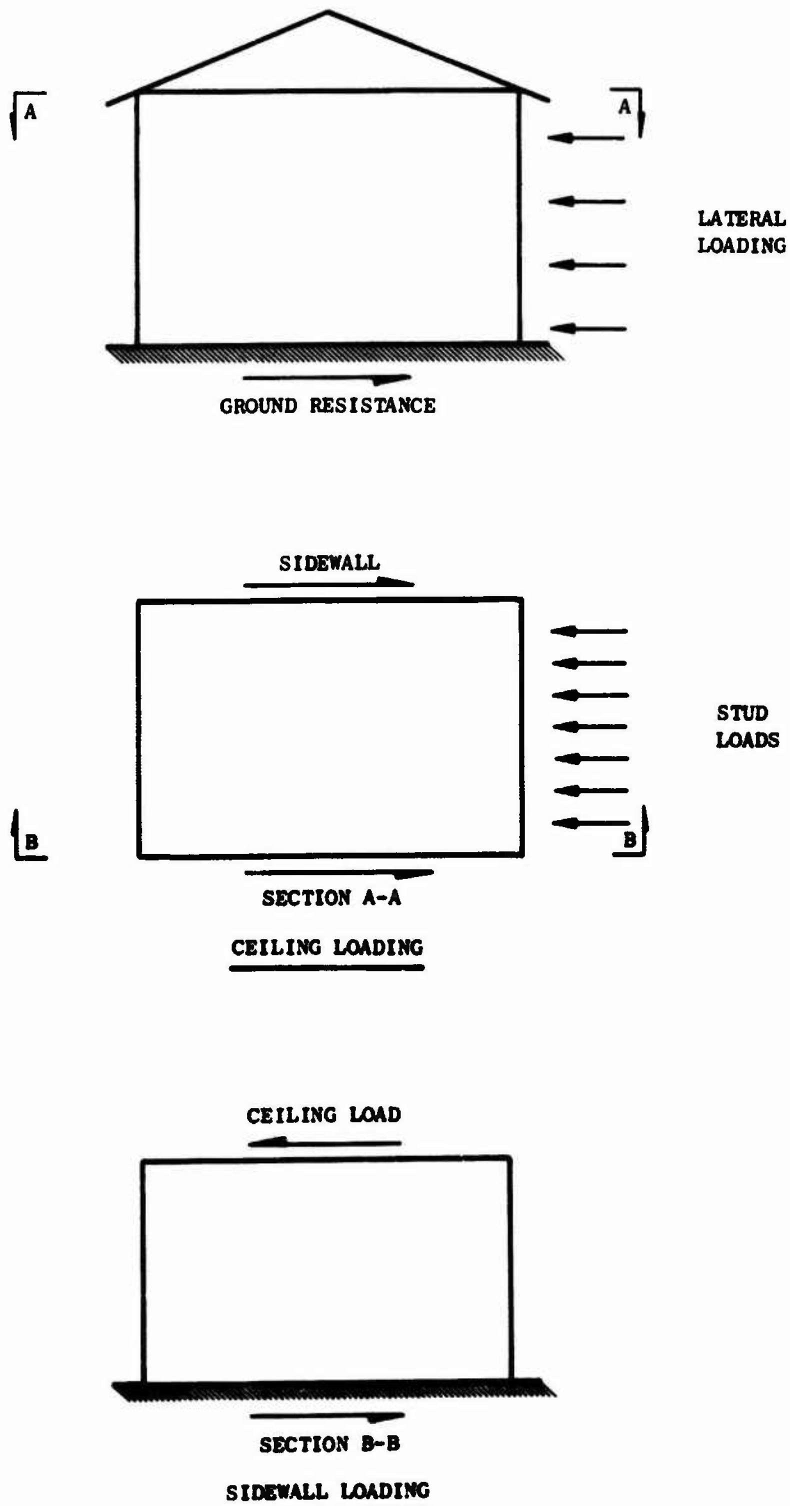
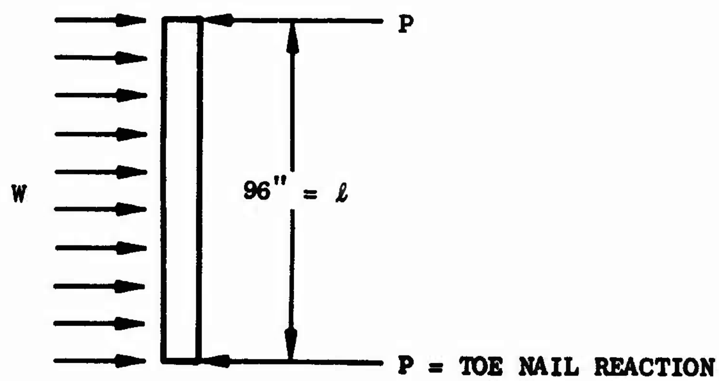


Fig. 11. Loading Sequence for Wood Frame Structure

that the built-in factor of safety for the lateral resistance of nails is much higher than that for wood bending stresses (5.5 compared to 2.25). The calculations are as follows:



$$w = \text{(c-c spacing)} \times \text{pressure}$$
$$= 16 \times p$$

$$w = \text{(c-c spacing)} \times \text{pressure}$$
$$= 16 \times p$$

$$w \times \ell = 2P$$

$$w = \frac{2P}{\ell}$$

For four-8-penny nails (average lateral resistance = 74 lb/nail, Ref. 19)

$$P = 74 \times 4 \times 5/6 \quad \text{(5/6 factor is for toe nails, Ref. 19)}$$
$$= 246$$

$$w = 16\ p = \frac{2P}{\ell}$$

$P = 0.323$ psi (average allowable static pressure, toe nail criterion)

Maximum bending moment for uniformly loaded, simply supported beam

$$M_{max} = \frac{w\ell^2}{8}$$

Maximum stress

$$\sigma_{max} = \frac{M}{S} \text{ (where S = section modulus = 3.56 in.}^3 \text{ for 2- by 4-in. stud)}$$

$$= 1624 \text{ psi (average)}$$

$$M_{max} = 1625 \times 3.56 = 5780 \text{ in.-lb}$$

$$= \frac{w\ell^2}{8}$$

$$= \frac{16p(96)^2}{8} = 1.84 \times 10^4 p$$

$$p = \frac{5780}{1.84} \times 10^4 = 0.31 \text{ psi (average allowable static pressure-bending rupture criterion)}$$

Diffraction Loading. First, considering overpressure effects, the reflected pressure (which for 1.2 psi overpressure is approximately 2.43) is formed almost instantly on the face of the building toward the blast. Rarefaction waves form at the edges of wall and at the openings and travel toward the center, relieving the higher reflected prossures.

The average time that the force generated by the reflected pressure and overpressure is on the structure can be approximated as follows:

$$t = \frac{3h}{U}$$

where

t is the clearing time

h is the clearing distance

U is the shock front velocity

From Ref. 15, it can be seen that the shock front velocity in the reflected

overpressure region at approximately 1.2 psi peak overpressure is 1160 ft/sec. and is independent of yield.

The structural model has windows spaced 3 ft apart. This makes the clearing distance approximately 1-1/2 ft.*

$$t = \frac{3 \times 1.5}{1160} = 0.0038 \text{ sec}$$

Dynamic analysis methods outlined in Ref. 11 are used. The uniformly loaded (the loads are time dependent, however) beam is analyzed as an equivalent single-degree-of-freedom spring mass system as follows:

I = Moment of inertia (in.^{4}) = 6.45 in.^{4} for 2- by 4-in. stud

E = Modulus of elasticity (psi)

W = Running weight (lb/in.)

M = Total mass (lb/sec^2/in.)

k = Spring constant (lb/in.)

m_e = Mass of equivalent system = mK_m

k_e = Spring constant of equivalent system = kK_R

T_n = Natural period of equivalent system = $2\pi\sqrt{\frac{m_e}{k_e}}$

T = Load duration

K_m = Mass factor = 0.5 for uniformly loaded beam (Ref. 11, p. 150)

K_R = Resistance factor = 16/25 for uniformly loaded beam (Ref. 11, p. 148 and 150)

---

* Use of 1-1/2 ft for clearing distance should provide an upper bound for the incident overpressure that would induce stud failure. Longer clearing distances (as for those portions of a structure remote from windows) or longer clearing times (if a window opening does not permit complete clearing in the least time) would result in lower overpressures to cause failure.

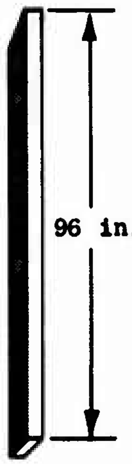
M = Bending moment (in.-lb)

S = Section modulus (in.^{3}) = 3.56 in.^{3} for 2- by 4-in. stud

B_e = Peak load

DLF = Dynamic load factor (Ref. 11, Fig. 7.12)

$E = 1.5 \times 10^6$ psi (average)



RUNNING WEIGHT $\approx$ 2.12 lb/in.

$$\text{TOTAL MASS} = \frac{2.12 \times 96}{386} = 0.528 \ \frac{\text{lb/sec}^2}{\text{in.}}$$

$$= m$$

$$k = \frac{384\,EI}{5l^3} = \frac{384 \times 1.5 \times 10^6 \times 6.45}{5(96)^3} = 80{,}500 \text{ lb/in. (spring constant)}$$

$$K_R = \frac{16}{25} \text{ (resistance factor)}$$

Equivalent System

$$m_e = mK_m = 0.525 \times 0.5 = 0.263 \ \frac{\text{lb/sec}^2}{\text{in.}}$$

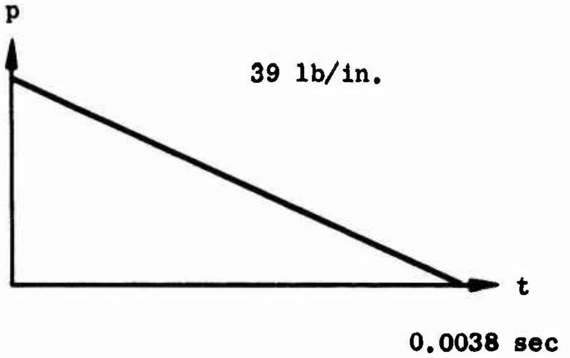
$$k_e = kK_R = 80500 \times \frac{16}{25} = 51{,}500 \text{ lb/in.}$$

$$\text{Natural period} = 2\pi\sqrt{\frac{m_e}{k_e}}$$

$$= 2\pi\sqrt{\frac{0.263}{0.0515 \times 10^6}}$$

$$= 0.0142 \text{ sec}$$

Reflected Pressure Loading



IDEALIZED LOADING CURVE

$$\frac{T}{T_n} = \frac{0.0038}{0.0142} = 0.27$$

$$DLF = 0.75$$

$$B_e = \text{Peak load} = \frac{16}{25} \times 39 \text{ lb/in.} \times 96 \text{ in.} = 2400 \text{ lb}$$

$$R_{m_e} = 2400 \times 0.75 = 1820$$

$$R_m = \frac{R_{m_e}}{K_R} = \frac{1820}{16/25} = 2850$$

$$\text{Bending Moment} = \frac{RL}{8} = \frac{2850 \times 96}{8} = 34.300 \text{ in./lb}$$

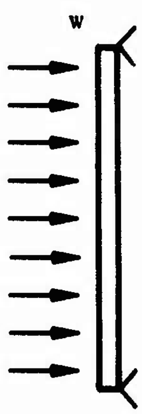
$$\text{Bending Stress} = \frac{M}{S} = \frac{34,300}{3.56} = 9,600 \text{ psi}$$

The above stress is for an overpressure of 1.2 psi. TM 23-200 indicates that severe damage would take place at approximately 3.5 psi overpressure for yields above 10 kt.

It should be noted that the stresses due to the overpressure are independent of the yield. This follows because nowhere in the above calculations does the time for positive overpressure enter. The clearing time, which is pertinent to the duration of the diffraction loading, is virtually unaffected by the yield and depends only on the overpressure.

Drag Loading

Consider now the drag-induced loading. From Ref. 15, a 1.2 psi peak overpressure results in a dynamic pressure of 0.035 psi. Drag coefficients are not closely defined in any of the literature, but values between 1.4 and 2.0 are common for flat faces. Assuming the upper value of 2.0, a drag loading can be calculated.



$$w = 16 \times C_D \times q$$

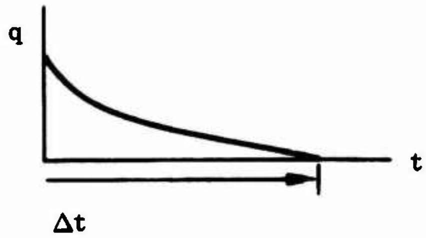
$$= 1.12 \text{ lb/in.}$$

= Running load

The drag loading, like the diffraction loading is suddenly applied. The biggest difference (aside from the magnitude) is the duration of loading. If the analysis is limited to yields above 10 kt, the dynamic load factor is 2.0, as in Table 4.

σ_q = stress due to drag force

$$= (\text{DLF}) \frac{WL^2}{8 \times 3.56} = 392 \ (\text{DLF})$$



$T = \Delta t$

$T_n = 0.0142$

Table 4

SUMMARY OF STRESS DUE TO DRAG FORCES

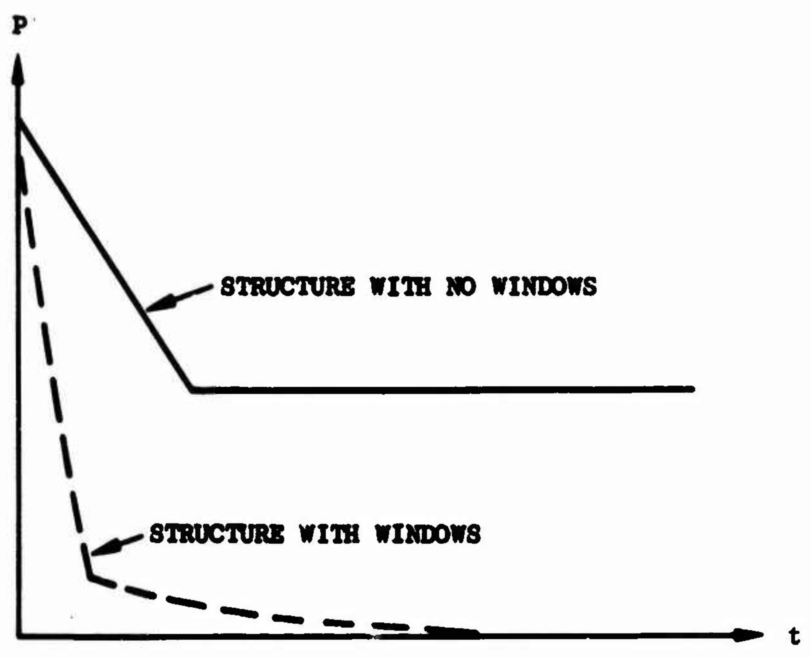
YIELD	OVERPRESSURE	t	$\frac{T}{T}$	DLF	STRESS DUE TO DRAG FORCES
10 kt	1.2 psi	1.08	76.	2.0	784 psi
30 kt	1.2 psi	1.55	109.	2.0	784 psi
100 kt	1.2 psi	2.32	164.	2.0	784 psi
1 Mt	1.2 psi	5.0	352.	2.0	784 psi
10 Mt	1.2 psi	10.8	760.	2.0	784 psi
30 Mt	1.2 psi	15.5	1,090.	2.0	784 psi
100 Mt	1.2 psi	32.2	1,640.	2.0	784 psi

Figure 3.49 of Ref. 15 shows that dynamic pressure rises at a faster rate than does the reflected pressure, i.e., $dq/dp > dp_r/dp$ when overpressure is the common scale. This might lead one to suspect that wood frame houses are somewhat drag sensitive. However, stresses due to drag loading are lower (approximately an order of magnitude) at all yields than those due to diffraction loading for the damage overpressure of 1.2 psi. Thus, it is concluded that the vulnerability of common wood frame structure (as measured by stud breakage) shows no yield dependency.

The failure level indicated by the above analysis is strongly dependent on the DLF applying to the diffraction loading. The DLF depends on the clearing time, which in turn depends on the clearing distance (or window spacing). For very open structures, the diffraction loading would be over in a relatively short time, causing the DLF to drop and allowing the structure to survive a larger overpressure.

For a wall with no openings, the DLF for diffraction loading would increase significantly, causing such a wall to fail at lower overpressures. However, failure would still be caused by the diffraction part of the loading.

In one of the nuclear tests in the Pacific (Ref. 20) a higher than expected yield was attained. This caused moderate overpressure (< 1.5 psi) on some wood frame structures, some 14-3/4 miles from GZ. Many of these suffered much structural distress but no complete collapse. These buildings were built with 2- by 4-in. studs placed 24 in. c.c. (much greater than the conventional 16 in. spacing for frame residences). They were covered with 3/8-in. plywood and had no windows. This last fact probably contributed most to their failure. Below are two force-time relationships, one for a load carrying member of a structure with no windows and one for a load carrying member of a structure with windows.



The impulse (area under the curve) is much greater for a structure with no windows. Thus, the existence of windows has an extremely important effect on the vulnerability of wood frame structures.

All the foregoing indicates that damage begins at about 1.2 psi. From all of the information that is available, severe damage (frame shattered and distorted so that the structure collapses or is on the verge of collapse) occurs at about 3.5 psi (Refs. 5 and 16). The overpressure that would produce 100-percent debris, (which for wood frame buildings is defined as complete collapse of the entire structure, with a large portion offsite) is still higher (estimated at 5 psi).

Although the pulse duration for megaton-range weapons is much longer than for kiloton weapons, it is felt that the dynamic pressure (less than 0.25 psi) existing at 3.5 psi overpressure is not sufficient to cause a wood frame building to become 100 percent debris, even after it undergoes severe damage. Accordingly, there appeared to be no basis for changing the debris curve for wood frame structures, which is 0 percent debris at about 2.0 psi to 100 percent at about 5 psi.

Finally, it should be recognized that the response of wood frame construction is not as predictable as that for other types of construction. Tests, such as the ones being carried out at present in the URS Shock Tunnel Facility, will serve to shed more light on the behavior of wood frame buildings and allow more precise predictions of damage and debris production.

Section 7

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Appendix A

DEBRIS PREDICTIONS FOR ALBUQUERQUE

Table A-1

DAMAGE DESCRIPTIONS

Structure No.	Description of Structure	Description of Damage: Severe	Moderate	Light
1	Wood frame residential	Frame shattered and distorted so that for the most part collapsed.	Wall framing cracked, roof badly damaged (many rafters failed, some sections collapsed), interior partitions distorted and partially removed. Wood floors distorted, general cracking and some breakage of joists.	Windows out, doors destroyed or off, interior partitions cracked.
2	Wall-bearing building, brick apartment house type; up to 3 stories.	Many bearing walls collapse, resulting in collapse of most of structure.	Exterior walls badly cracked, interior partitions cracked, distorted and partially removed.	Windows out, doors destroyed or off, interior partitions cracked.
3	Wall-bearing masonry building, monumental type; up to 4 stories.	Many bearing walls collapse resulting in collapse of structure supported by these walls; some bearing walls may be shielded enough by intervening walls so that part of the structure may receive only moderate damage.	Exterior walls facing blast badly cracked, interior partitions cracked and distorted and partially removed. Toward far end of building damage may be reduced.	Windows out, doors destroyed or off, interior partitions cracked.
4	Reinforced masonry building with concrete or reinforced masonry spandrels.	Walls shattered, severe wall and floor distortion, incipient collapse.	Exterior walls badly cracked, interior partitions cracked, distorted and partially removed. Structural elements (floors, roof, framing, etc.) distorted, extensive cracking and spalling or masonry.	Windows out, doors destroyed or off, interior partitions cracked.
5	Light steel frame industrial building, single story, with up to 5-ton crane capacity. Lightweight, low-strength sheathing.	Severe distortion or collapse of frame.	Some distortion of frame, girts and purlins. Cranes (if any) not operable until repairs made.	Windows out, doors destroyed or off, light sheathing removed.
6	Medium steel frame industrial building, single story, with 25-30-ton crane capacity. Lightweight, low-strength sheathing.	Severe distortion or collapse of frame.	Some distortion of frame, girts and purlins, cranes not operable until repairs made.	Windows out, doors destroyed or off, light sheathing removed.
7	Heavy steel frame industrial building, single story, with 60- 100-ton crane capacity. Lightweight, low-strength sheathing.	Severe distortion or collapse of frame.	Some distortion of frame, girts and purlins, cranes not operable until repairs made.	Windows out, doors destroyed or off, light sheathing removed.
8	Multistory steel frame office type building, 3- 10 stories (non-earthquake-resistant construction), low-strength panels.	Severe frame distortion, incipient collapse.	Some frame distortion, panels and partitions removed.	Windows out, doors destroyed or removed, light siding removed, interior partitions cracked.
9	Multistory steel frame office type building, 3- 10 stories (earthquake-resistant construction), low-strength panels.	Severe frame distortion, incipient collapse.	Some frame distortion, panels and partitions removed.	Windows out, doors destroyed or removed, light siding removed, interior partitions cracked.
10	Multistory reinforced concrete frame office type building, 3 - 10 stories (non-earthquake-resistant construction), low-strength panels.	Severe frame distortion, incipient collapse.	Some frame distortion, panels and partitions removed. Some floor and roof damage. General spalling of concrete at beam-column connections.	Windows out, doors destroyed or removed, light siding removed, interior partitions cracked.
11	Multistory reinforced concrete frame office type building, 3 - 10 stories (earthquake-resistant construction), low-strength panels.	Severe frame distortion, incipient collapse.	Some frame distortion, panels and partitions removed. Some floor and roof damage. General spalling of concrete at beam-column connections.	Windows out, doors destroyed or removed, light siding removed, interior partitions cracked.
12	Multistory heavy reinforced concrete shear wall building.	Walls shattered, severe floor and wall diaphragm distortion, incipient collapse.	Walls breached or on the point of being so, structure permanently racked. Extensive spalling of concrete. Interior partitions badly distorted or destroyed.	Windows out, doors destroyed or removed, interior partitions cracked.
13	Multistory light reinforced concrete shear wall building.	Walls shattered, severe floor and wall diaphragm distortion, incipient collapse.	Exterior walls breached or on the point of being so, interior partitions badly distorted or destroyed. Structure permanently racked, extensive spalling of concrete.	Windows out, doors destroyed or removed, interior partitions cracked.
14	Light reinforced concrete shear wall building, single story, with mill type roof.	Severe distortion of walls and roof frame. Incipient collapse.	Some distortion of walls and roof frames, interior panels removed.	Windows out and doors destroyed or off, light roof sheathing removed, interior partitions cracked.
15	Light reinforced concrete shear wall building with light concrete roof.	Severe distortion of walls and roof beams. Incipient collapse.	Some distortion of walls, roof slabs partially punched out.	Windows out and doors destroyed or off, interior partitions cracked.

Table A-2

RANGES (in kilometers) FOR BUILDING DAMAGE IN ALBUQUERQUE

Structure		Severe	Moderate	Light
1	Wood frame residential	15.0	17.6	31.0
2	Wall-bearing building, brick apartment house type; up to 3 stories.	11.0	13.0	
3	Wall-bearing masonry building, monumental type; up to 4 stories.	7.5	9.5	
4	Reinforced masonry building with concrete or reinforced masonry spandrels.	2.5	4.0	
5	Light steel frame industrial building, single story, with up to 5-ton crane capacity. Lightweight, low-strength sheathing.	10.0	11.5	
6	Medium steel frame industrial building, single story, with 25-30-ton crane capacity. Lightweight, low-strength sheathing.	7.7	9.2	
7	Heavy steel frame industrial building, single story, with 60- 100-ton crane capacity. Lightweight, low-strength sheathing.	5.0	7.5	
8	Multistory steel frame office type building, 3-10 stories (non-earthquake-resistant construction), low-strength panels.	5.3	7.7	
9	Multistory steel frame office type building, 3-10 stories (earthquake-resistant construction), low-strength panels.	3.0	7.5	
10	Multistory reinforced concrete frame office type building, 3-10 stories (non-earthquake-resistant construction), low-strength panels.	6.0	7.2	
11	Multistory reinforced concrete frame office type building, 3-10 stories (earthquake-resistant construction) low-strength panels.	2.7	7.5	
12	Multistory heavy reinforced concrete shear wall building.	-	2.5	
13	Multistory light reinforced concrete shear wall building.	5.0	9.0	
14	Light reinforced concrete shear wall building, single story, with mill type roof.	7.3	11.5	
15	Light reinforced concrete shear wall building with light concrete roof.	7.3	10.0	

NOTE: Light damage occurs at 1 psi overpressure.

Table A-3

DEBRIS DESCRIPTIONS

I. Commercial - With Fire

	TYPICAL COMPOSITION	
	BUILDING CONTENTS	STRUCTURAL DEBRIS
A. Light	Counter-top furnishings Desk-top furnishings	Glass Doors Suspended ceilings Roofing materials Roof ventilators Corrugated asbestos and iron siding Plaster Suspended lighting fixtures Signs attached to structure
B. Medium	Office furniture Office machines Vending machines	Light partitions Light metal curtain walls Lighting fixtures Light roof decks on metal trusses
C. Heavy	Full filing cabinets Safes	Roof decks Floor decks Steel and reinforced concrete framing members Plumbing fixtures Mechanical equipment

Table A-3, cont.

I. Commercial - Without Fire

	TYPICAL COMPOSITION	
	BUILDING CONTENTS	STRUCTURAL DEBRIS
A. Light	Desk-top furnishings Counter-top furnishings Magazines Hanging clothing Books	Glass Doors Suspended ceilings Roofing materials Roof ventilators Heating ductwork Signs attached to structure Corrugated asbestos and iron siding Plaster Suspended lighting fixtures
B. Medium	Office furniture Office machines Display cases Vending machines	Light wood sheathing Light partitions Light metal curtain walls Lighting fixtures Light roof decks on metal trusses
C. Heavy	Full filing cabinets Safes	Light roof decks Light floor decks Heavy partitions Wood studs, joists, and rafters Plumbing fixtures Mechanical equipment

Table A-3, cont.

II. Industrial - With Fire

	TYPICAL COMPOSITION	
	BUILDING CONTENTS	STRUCTURAL DEBRIS
A. Light	Trash cans Light warehoused materials	Glass Metal doors Roofing materials Roof ventilators Suspended heaters Suspended lighting fixtures Corrugated asbestos and iron siding Signs attached to structure
B. Medium	Light industrial machinery Hand tools Vending machines Medium warehoused material	Light partitions Light metal curtain walls Lighting fixtures Light roof decks on metal trusses
C. Heavy	Heavy industrial machinery Industrial trucks Heavy warehoused material	Overhead cranes Light roof decks Light floor decks Mechanical equipment

Table A-3, cont.

II. Industrial - Without Fire

	TYPICAL COMPOSITION	
	BUILDING CONTENTS	STRUCTURAL DEBRIS
A. Light	Rags Papers Trash cans Light warehoused material	Glass Doors Roofing materials Roof ventilators Suspended heaters Suspended lighting fixtures Corrugated asbestos and iron siding
B. Medium	Light industrial machinery Hand tools Vending machines Medium warehoused material	Light wood sheathing Light partitions Light metal curtain walls Lighting fixtures Light roof decks on metal trusses
C. Heavy	Heavy industrial machinery Industrial trucks Heavy warehoused material	Overhead cranes Light roof decks Light floor decks Wood studs, joists, and rafters Plumbing fixtures Mechanical equipment

Table A-3, cont.

III. Residential - With Fire

	TYPICAL COMPOSITION	
	BUILDING CONTENTS	STRUCTURAL DEBRIS
A. Light	Small appliances	Glass Roofing materials Roof ventilators
B. Medium	Light furniture	No change from light category
C. Heavy	Heavy furniture Major appliances Automobiles (in garage)	Furnaces Water heaters Plumbing fixtures

Table A-3, cont.

III. Residential - Without Fire

	TYPICAL COMPOSITION	
	BUILDING CONTENTS	STRUCTURAL DEBRIS
A. Light	Lamp Shades Drapes Linens Magazines Dishes Small appliances Books	Glass Doors Roofing materials Roof ventilators
B. Medium	Light furniture	Light wood sheathing
C. Heavy	Heavy furniture Major appliances Automobiles (in garage)	Wood studs, joists, and rafters Furnaces Water heaters Plumbing fixtures

Table A-4

SAMPLE AREA DEBRIS CHARACTERISTICS

SBM*	BOUNDARY STREETS	PSI	STRUCTURAL TYPE**	OCCUPANCY % OF AREA	DEBRIS CHARACTERISTICS***		REMARKS
					BLAST ONLY	BLAST AND FIRE	
210	Sierra Place Valverde Drive Smith Avenue Morningside Drive	8.0	1 2	Residential 100%	C	C	
207	Solano Drive Coal Drive Tulane Drive Silver Avenue	6.8	1 2	Residential 100%	C	C	
205	Morningside Drive Grand Avenue Amherst Drive Lomas Blvd	6.8	1 2	Residential 100%	C	C	
213	Highland Avenue Girard Blvd Garfield Avenue Buena Vista Drive	5.7	1 2	Residential 100%	C	C	Adobe and load-bearing wall residences give medium debris
201	Bryn Mawr Drive Central Avenue Montevista Blvd	6.4	2 15	Commercial 100%	B	B	

* Sanborn Map Sheet Number

** Refer to Table A-1

*** Refer to Table A-3

Table A-4, cont.

SBM*	BOUNDARY STREETS	PSI	STRUCTURAL TYPE**	OCCUPANCY % OF AREA	DEBRIS CHARACTERISTICS		REMARKS
					BLAST ONLY	BLAST AND FIRE	
3	Central Avenue 1st Street Alley south of Gold 2nd Street	3.7	2	Commercial 100%	A	A	
1	Tijeras Avenue 3rd Street Copper Avenue 4th Street	3.5	15	Commercial 100%	A	A	Fedway Department Store
1-A	Tijeras Avenue 2nd Avenue Copper Avenue 3rd Street	3.8	2 3	Commercial 100%	A	A	Sheet contains City Hall and jail
1-I	Copper Avenue 3rd Street Alley south of Central 4th Street	3.8	2 10	Commercial 100%	A	A	Sheet contains Mountain States Telephone & Telegraph Co. which is essentially undamaged
1-I	Alley south of Central 3rd Street Silver Avenue 4th Street	3.8	2 9 10	Commercial 100%	A	A	Sheet contains 14-story Bank of New Mexico Building that will contribute a large amount of ejected contents

Table A-4, cont.

SBM*	BOUNDARY STREETS	PSI	STRUCTURAL TYPE**	OCCUPANCY % OF AREA	DEBRIS CHARACTERISTICS***		REMARKS
					BLAST ONLY	BLAST AND FIRE	
1-H	Alley south of Central 4th Street Silver Avenue 5th Street	3.7	2 9		A	A	13-story Simms Building will contribute a large amount of ejected contents
6	Alley south of Central 4th Street Lead Avenue 6th Street	3.5	1 2 9	Commercial 80% Residential 20%	A C	A C	Post Office and Federal Building on this sheet. There are large open areas around residences which would be essentially debris-free.
9	Roma Avenue 4th Street Tijeras Avenue 6th Street	3.4	1 2 9 11	Commercial 70% Residential 30%	A C	A C	Sheet includes Municipal Office Building and Hall of Justice
10	Roma Avenue 2nd Street Tijeras Avenue 4th Street	3.5	2 15	Commercial 70% Industrial 30%	A A	A A	All single-story buildings
2	Grand Avenue A.T. & S.F. R.R. Central Avenue 1st Street	3.8	2 15	Commercial 100%	A	A	

Table A-4, cont.

SBM*	BOUNDARY STREETS	PSI	STRUCTURAL TYPE**	OCCUPANCY % OF AREA	DEBRIS CHARACTERISTICS***		REMARKS
					BLAST ONLY	BLAST AND FIRE	
1-D	Copper Avenue 4th Street Alley south of Central 5th Street	3.8	2	Commercial 100%	A	A	
1-F	Copper Avenue 2nd Avenue Alley south of Central 3rd Avenue	3.8	2 8 10	Commercial 100%	A	A	
1-C	Copper Avenue 5th Street Alley south of Central 6th Street	3.7	2 10	Commercial 100%	A	A	
1-G	Tijeras Avenue 1st Street Central Avenue 2nd Street	3.8	2 10	Commercial 100%	A	A	
1-J	Alley south of Central 2nd Street Silver Avenue 3rd Street	3.8	2	Commercial 100%	A	A	

Table A-4, cont.

SBM*	BOUNDARY STREETS	PSI	STRUCTURAL TYPE	OCCUPANCY % OF AREA	DEBRIS CHARACTERISTICS***		REMARKS
					BLAST ONLY	BLAST AND FIRE	
8	Tijeras Avenue 4th Street Copper Avenue 6th Street	3.5	2 15	Commercial 100%	A	A	
8	Silver Avenue 2nd Street Lead Avenue 4th Street	3.7	2	Commercial 100%	A	A	Sheet contains St. Johns Episcopal Cathedral
4	Central Avenue A.T. & S.F. R.R. Lead Avenue 2nd Street	3.7	2	Commercial 100%	A	A	Much vacant land
7	Tijeras Avenue 5th Street Central Avenue 8th Street	3.4	1 2	Commercial 70% Residential 30%	A B	A B	
11	Mountain Road A.T. & S.F. R.R. Slate Avenue 3rd Street	3.7	1 2	Commercial 40% Industrial 20% Residential 40%	B B C	B B C	

Table A-4, cont.

SBM*	BOUNDARY STREETS	PSI	STRUCTURAL TYPE**	OCCUPANCY % OF AREA	DEBRIS CHARACTERISTICS***		REMARKS
					BLAST ONLY	BLAST AND FIRE	
48	Tijeras Avenue Locust Street Gold Avenue Elm Street	4.5	1 2 12	Commercial 100%	B	B	A.T. & S.F. R.R. Hospital is structurally undamaged, but contents are heavily damaged
5	Central Avenue 6th Street Lead Avenue 8th Street	3.5	1 2 10	Commercial 80% Residential 20%	B C	B C	
56	Cromwell Avenue Dan Avenue High Street Arno Street	4.4	1 2	Residential 100%	C	C	Adobe and load-bearing wall residences give medium debris
47	Las Lomas Road University Blvd Copper Avenue Sycamore	4.7	1 2	Residential 100%	C	C	Adobe and load-bearing wall residences give medium debris
35	Mountain Road Forrester Avenue Roma Avenue 14th Street	3.0	1 2	Residential 100%	B	C	Adobe and load-bearing wall residences give light debris

Table A-4, cont.

SBM*	BOUNDARY STREETS	PSI	STRUCTURAL TYPE**	OCCUPANCY % OF AREA	DEBRIS CHARACTERISTICS***		REMARKS
					BLAST ONLY	BLAST AND FIRE	
30	Park Avenue Raynolds Avenue Kit Carson Avenue	2.8	1 2	Residential 100%	B	A	Adobe and load-bearing wall residences give light debris
51	Gold Avenue Pine Street Coal Avenue Spruce Street	4.8	1 2	Residential 100%	C	C	Adobe and load-bearing wall residences give medium debris
45	Grand Avenue Elm Street Copper Avenue Edith Blvd	4.4	1 2	Residential 100%	C	C	Adobe and load-bearing wall residences give medium debris
49	Gold Avenue Elm Street Coal Avenue Broadway	4.2	1 2	Residential 100%	C	C	Adobe and load-bearing wall residences give medium debris
22	Stover Avenue 2nd Street Santa Fe Avenue 4th Street	3.7	1 2	Commercial 20% Residential 80%	C B	C B	Adobe and load-bearing wall residences give medium debris

URS 686-4

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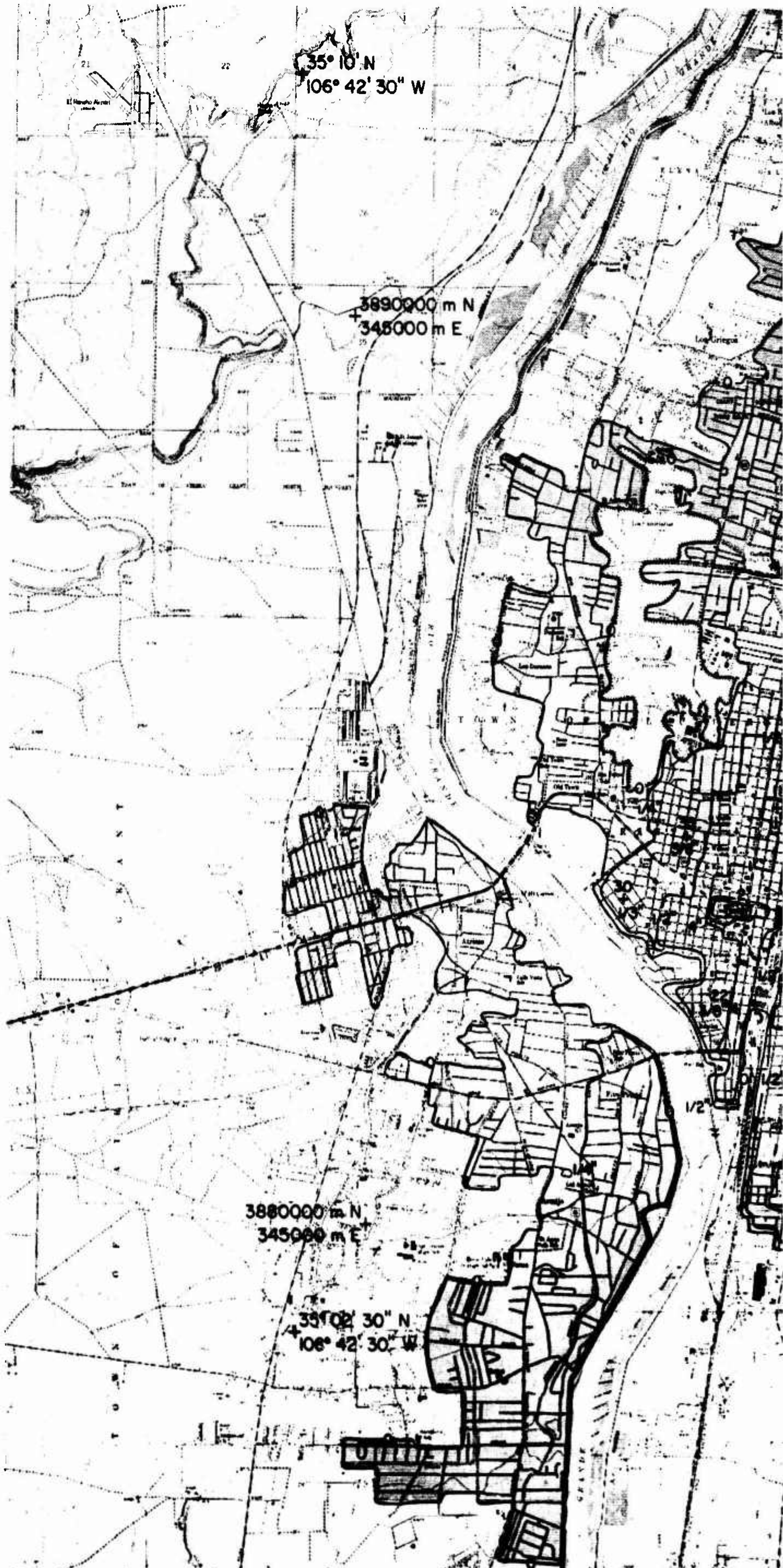

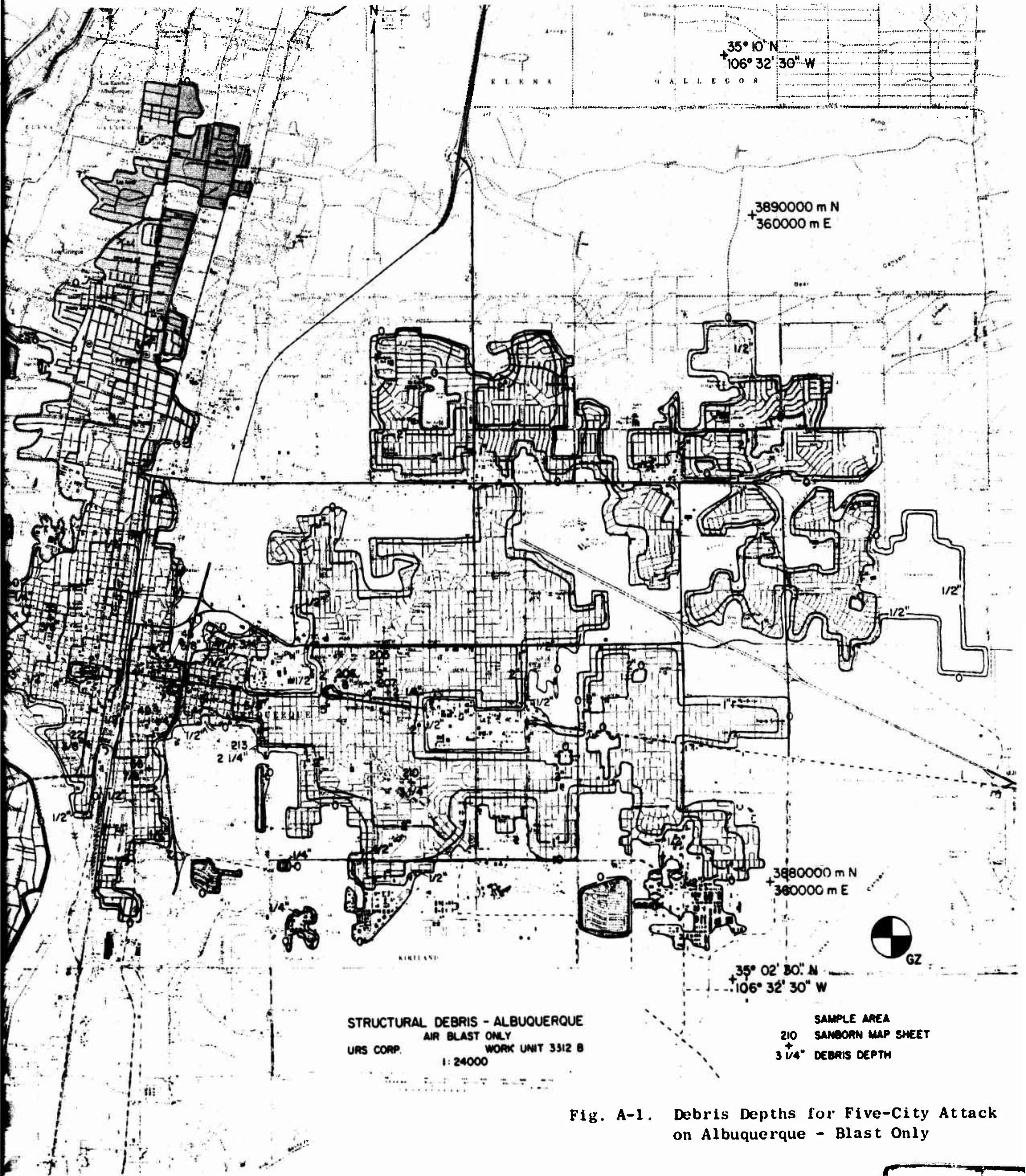

Fig. A-1. Debris Depths for Five-City Attack on Albuquerque - Blast Only

2

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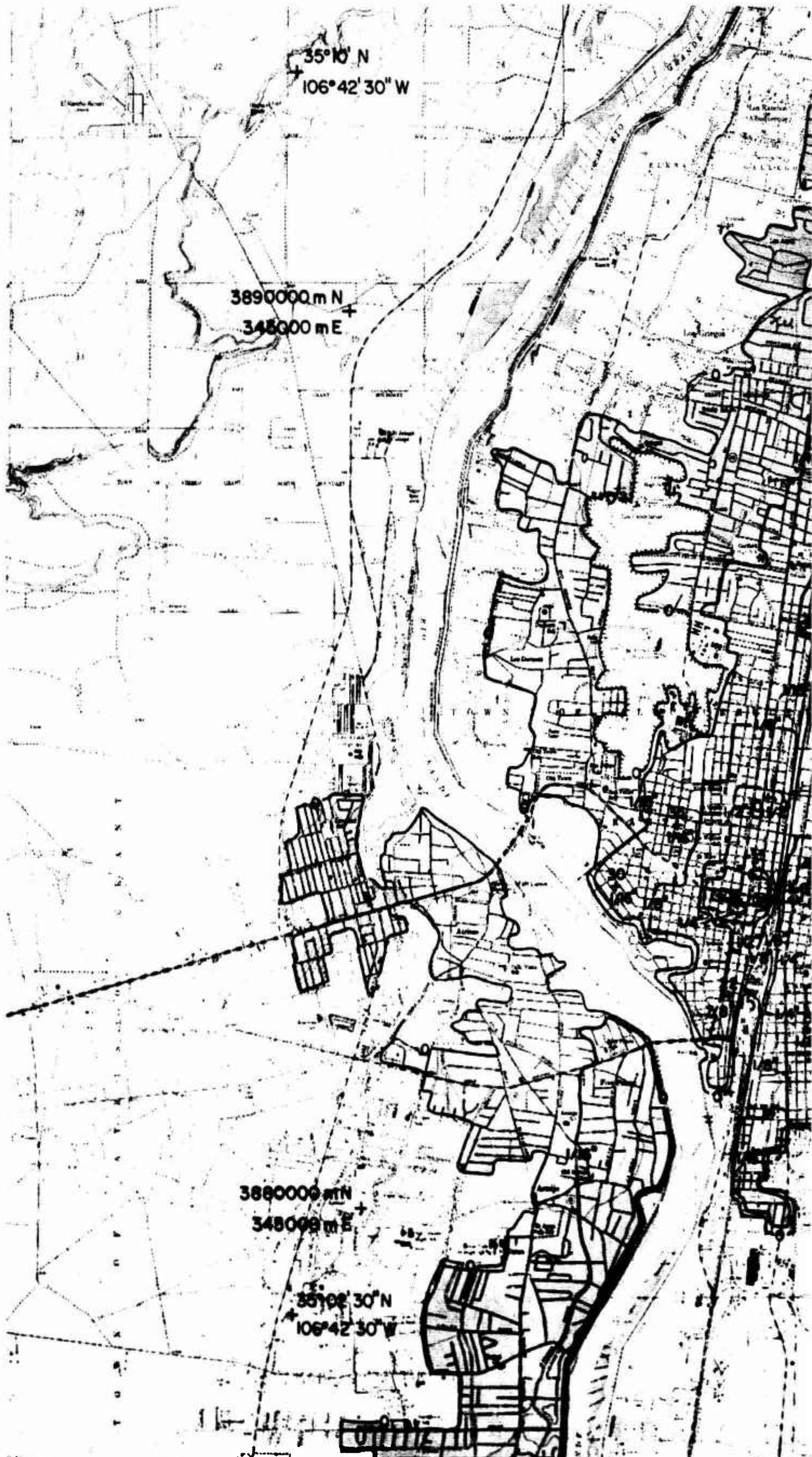

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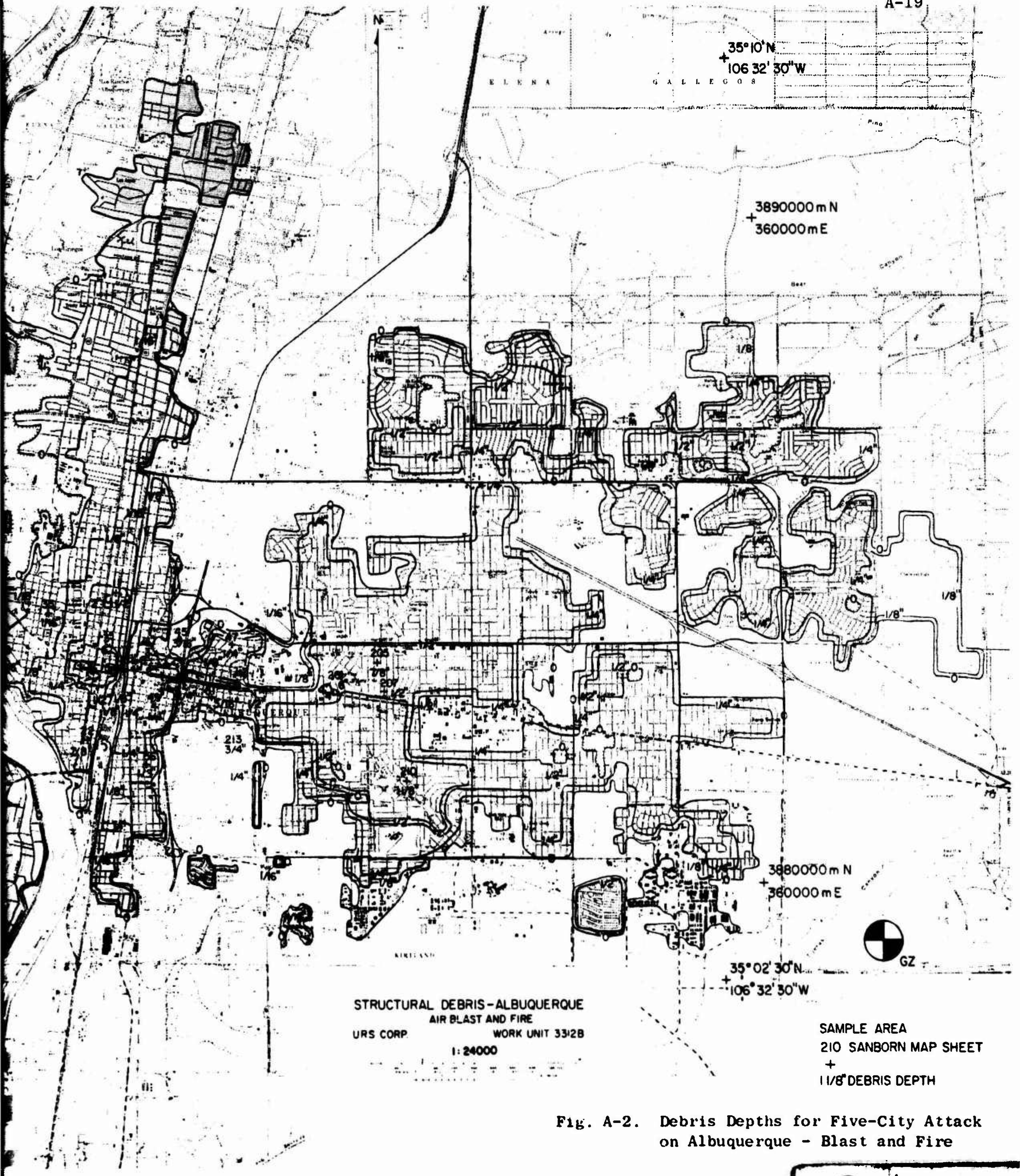

Fig. A-2. Debris Depths for Five-City Attack on Albuquerque - Blast and Fire

Appendix B

DEBRIS CHARTS

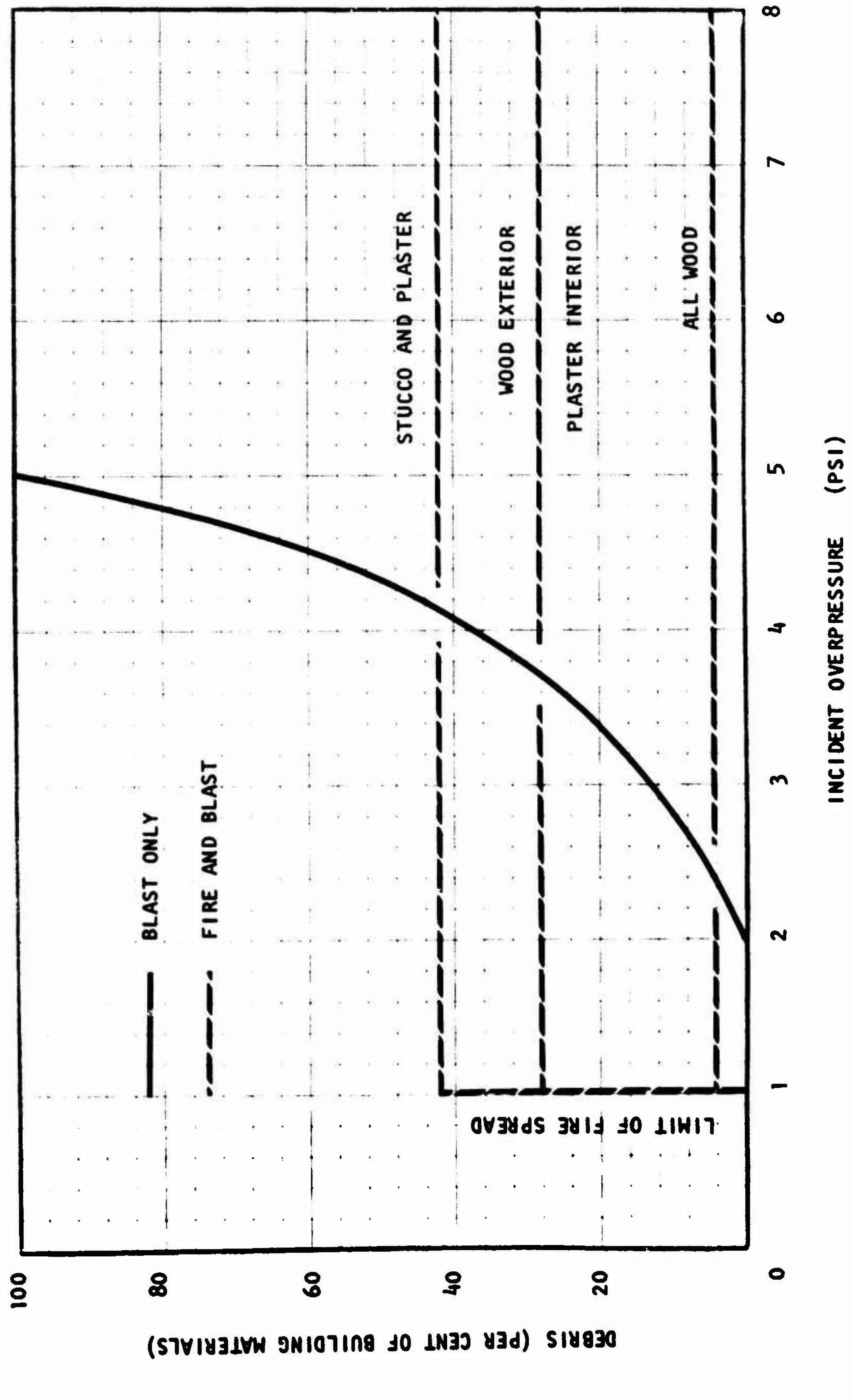

Fig. B-1. Percent Debris vs Overpressure - Wood Frame Building

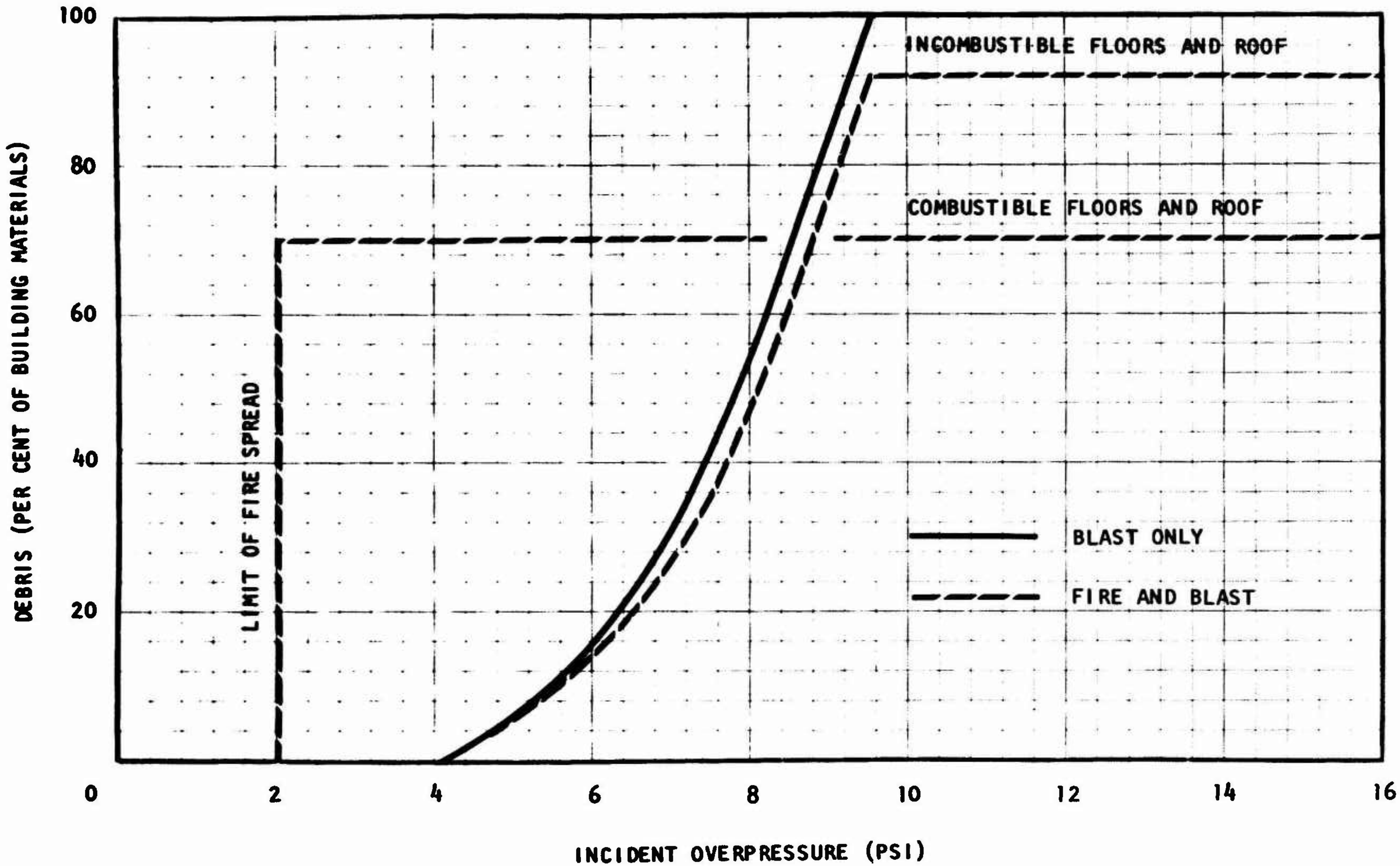

Fig. B-2. Percent Debris vs Overpressure — Unreinforced Masonry Load-Bearing Wall Building

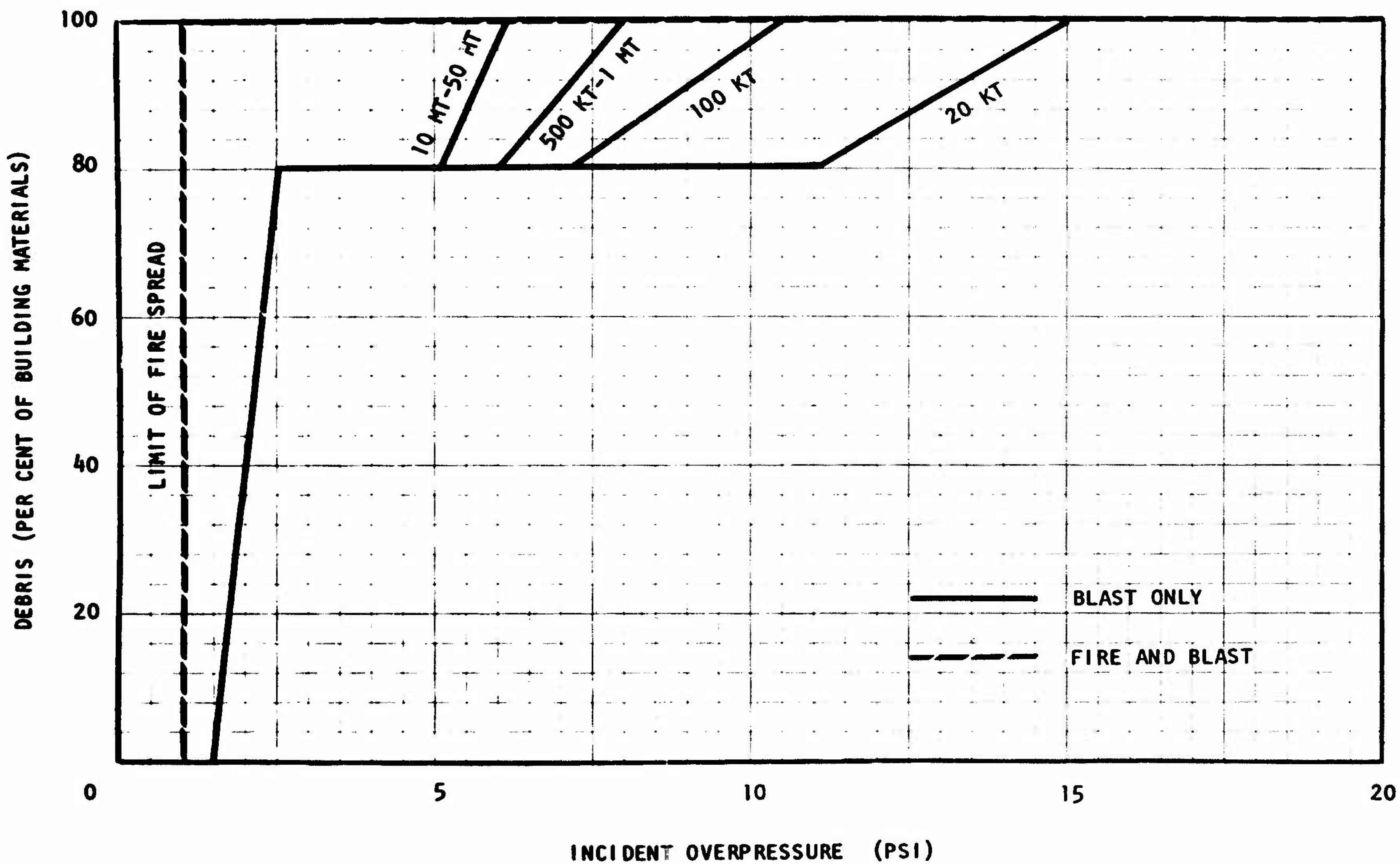

Fig. B-3. Percent Debris vs Overpressure — Light Steel Frame Industrial Building (up to 25-ton crane) with Corrugated Asbestos Sheathing

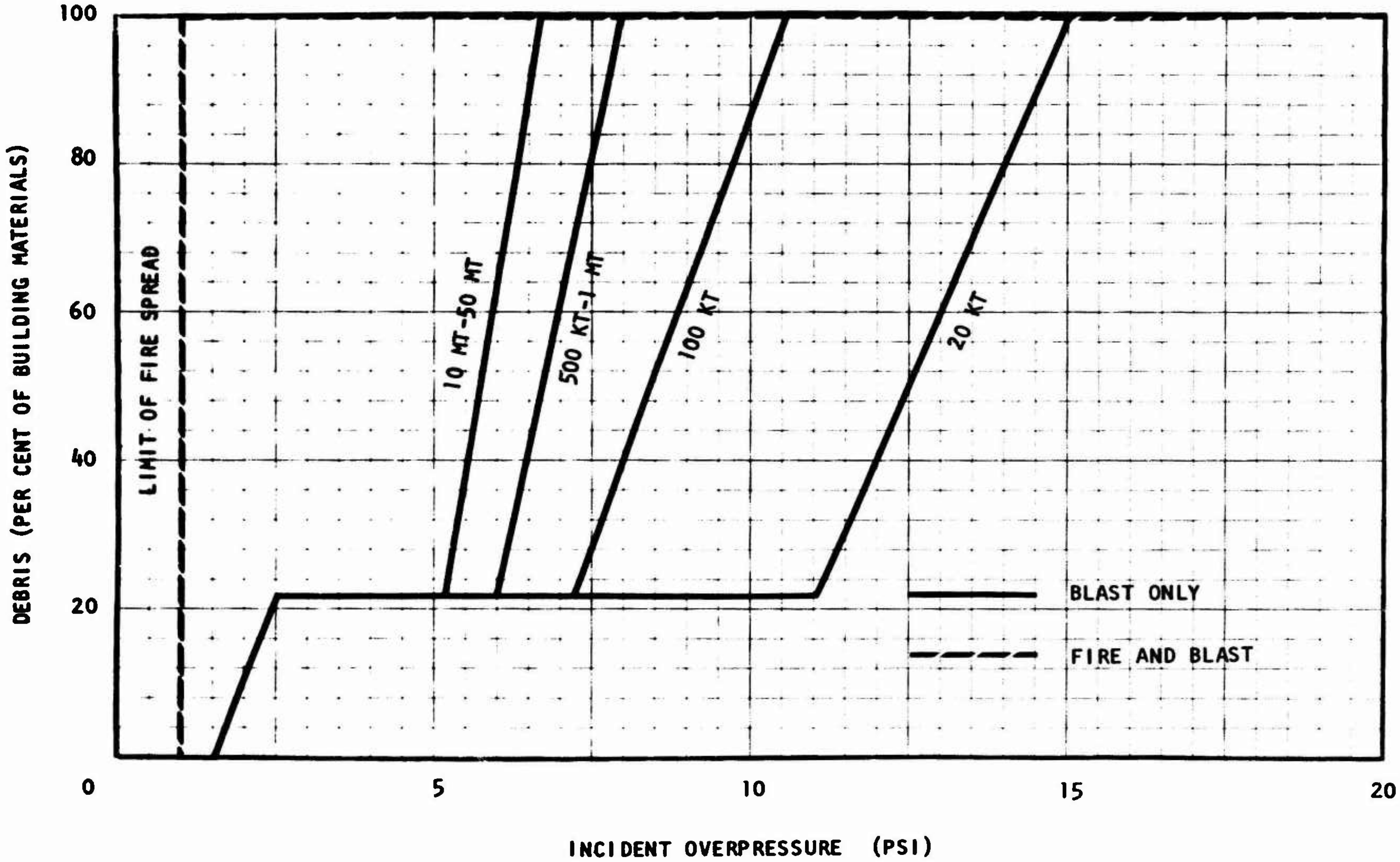

Fig. B-4. Percent Debris vs Overpressure — Light Steel Frame Industrial Building (up to 25-ton crane) with Corrugated Metal Sheathing

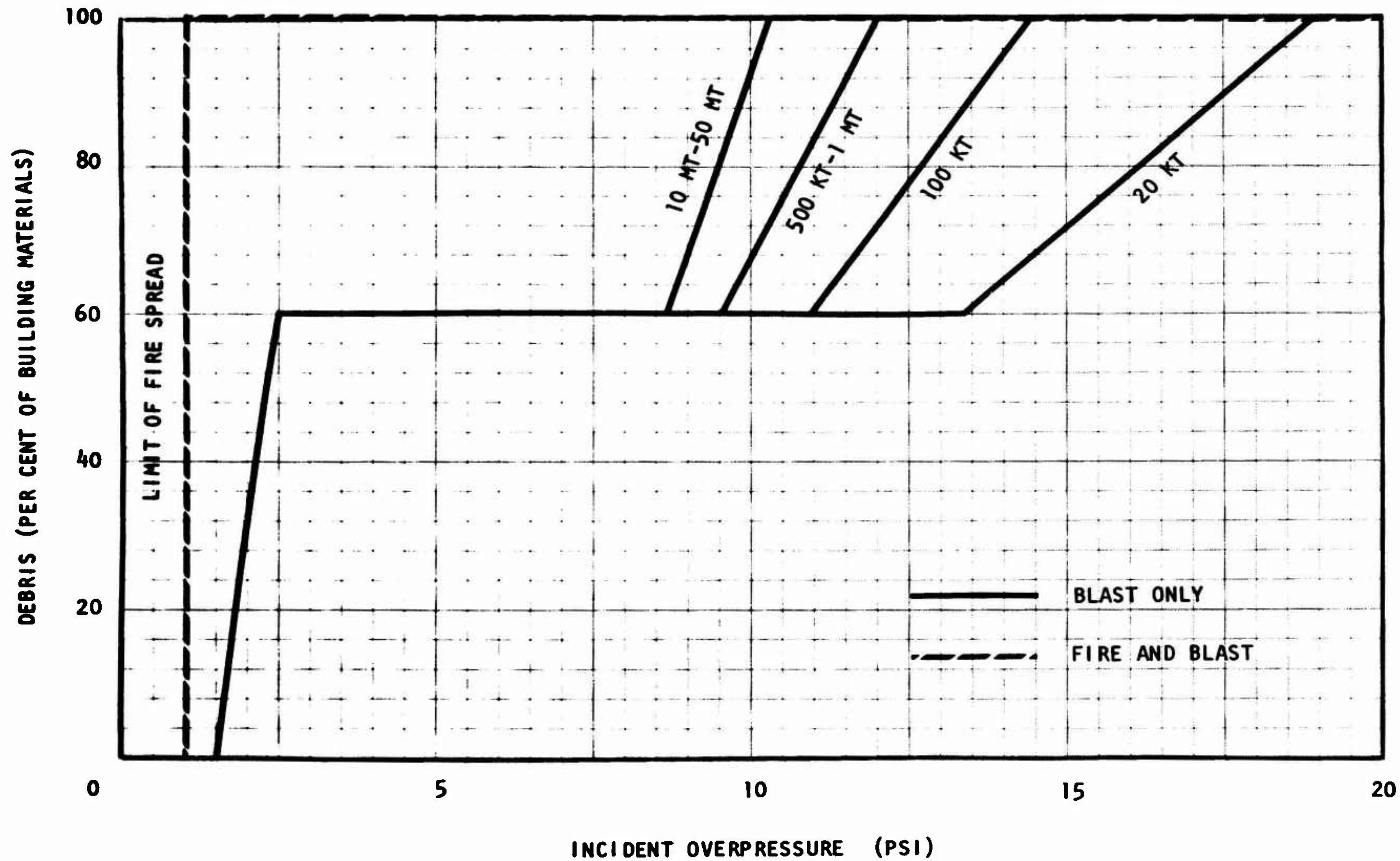

Fig. B-5. Percent Debris vs Overpressure — Medium Steel Frame Industrial Building (25- to 50-ton crane) with Corrugated Asbestos Sheathing

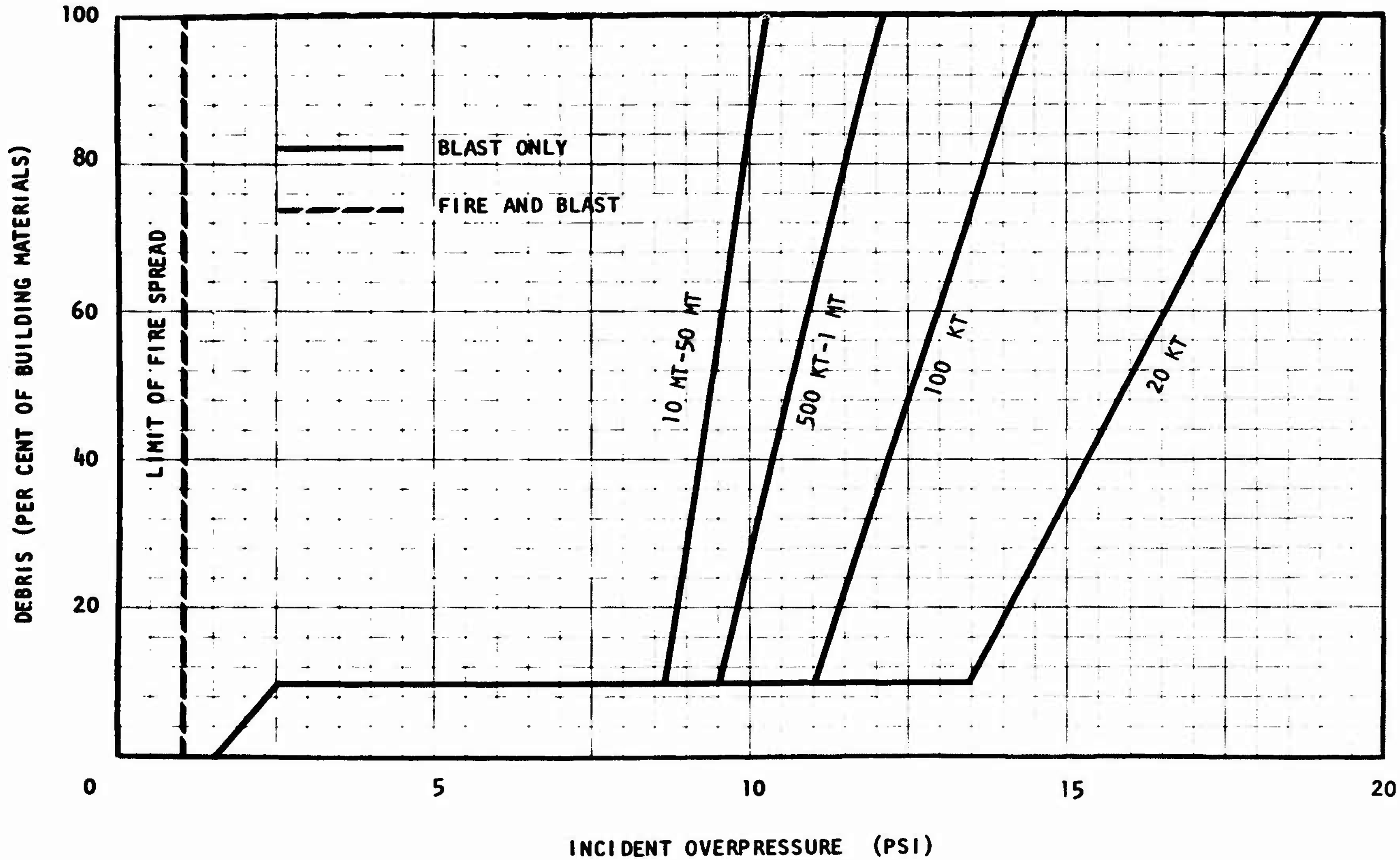

Fig. B-6. Percent Debris vs Overpressure — Medium Steel Frame Industrial Building (25- to 50-ton crane) with Corrugated Metal Sheathing

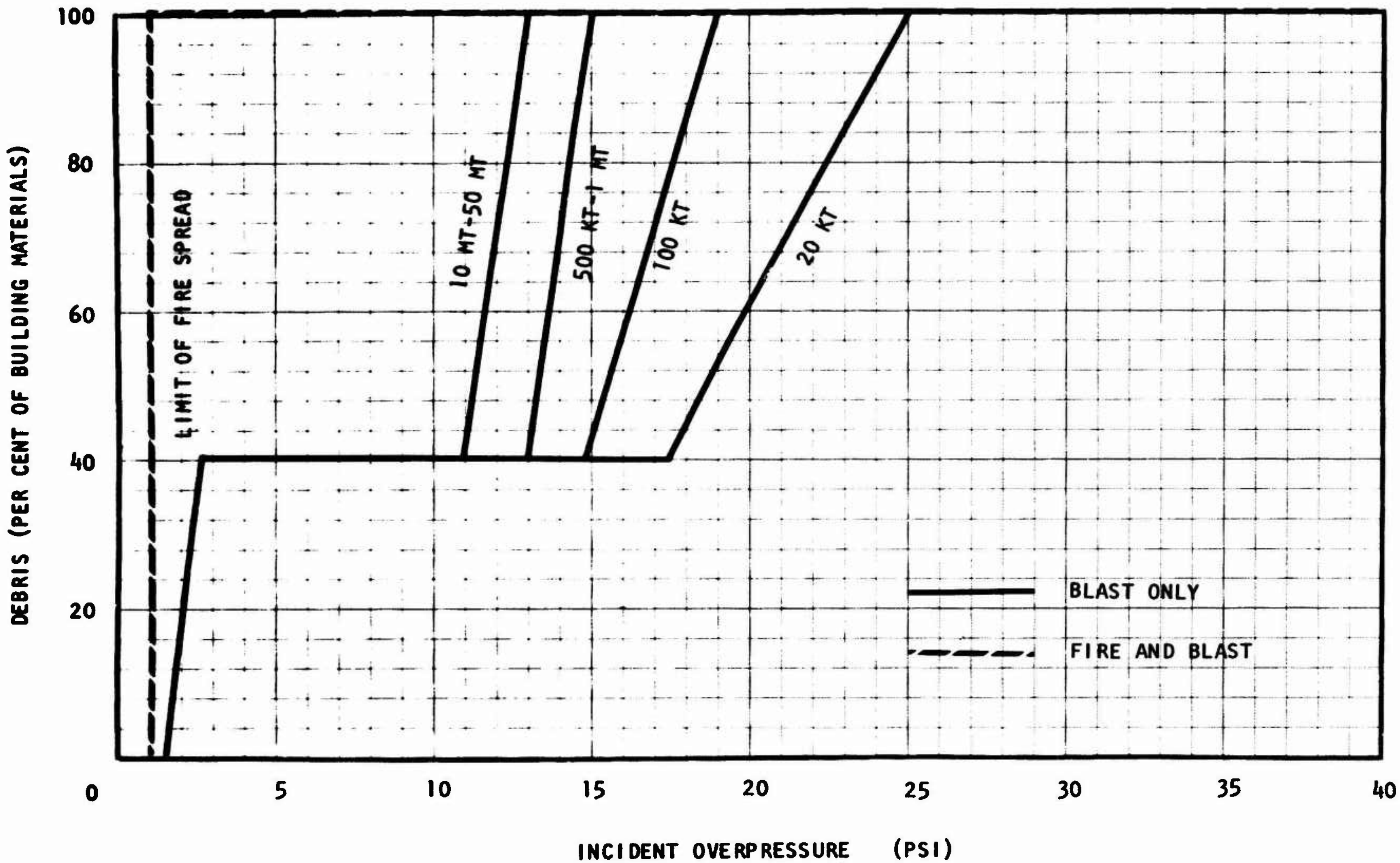

Fig. B-7. Percent Debris vs Overpressure — Heavy Steel Frame Industrial Building (60- to 100-ton crane) with Corrugated Asbestos Sheathing

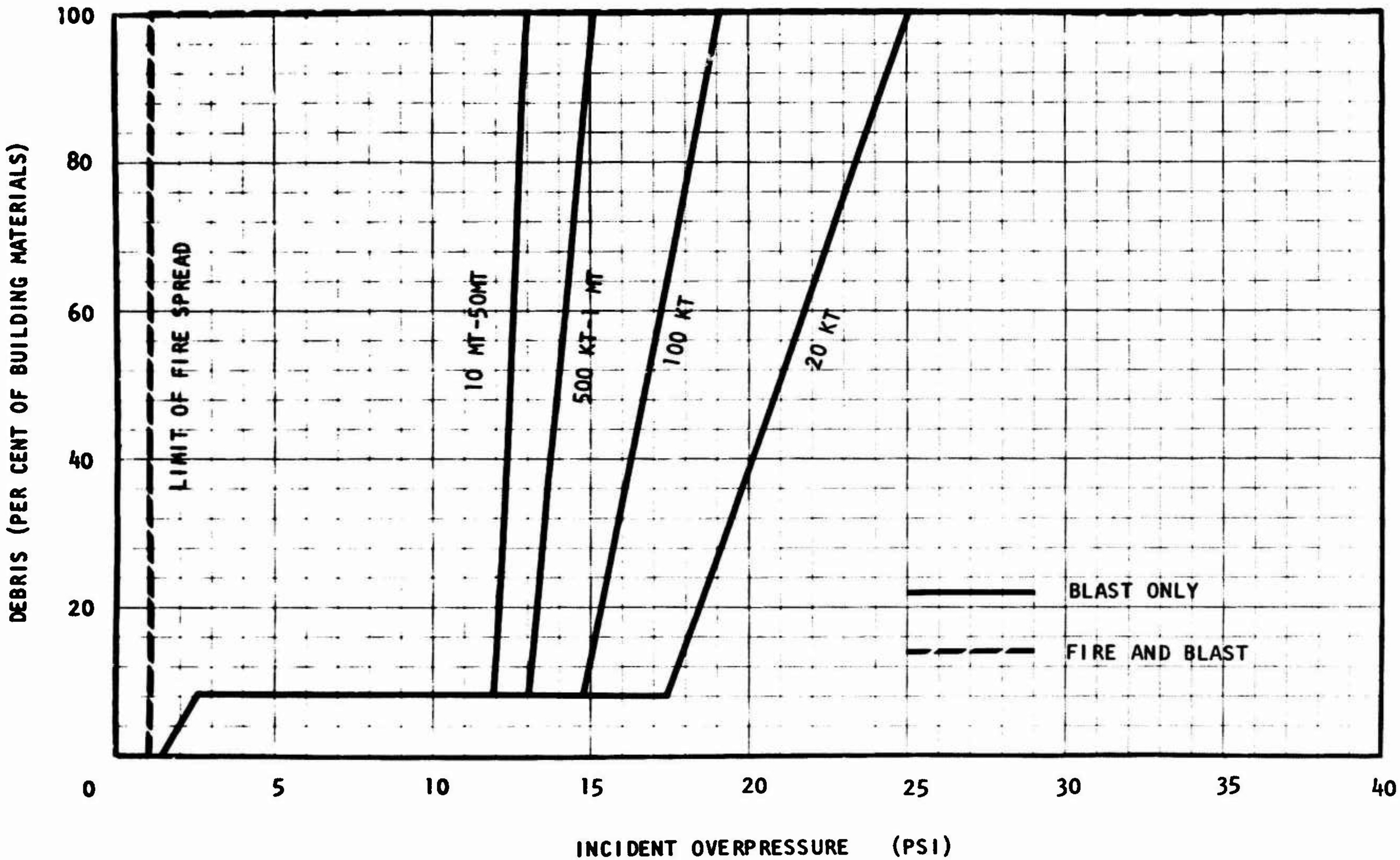

Fig. B-8. Percent Debris vs Overpressure — Heavy Steel Frame Industrial Building (60- to 100-ton crane) with Corrugated Metal Sheathing

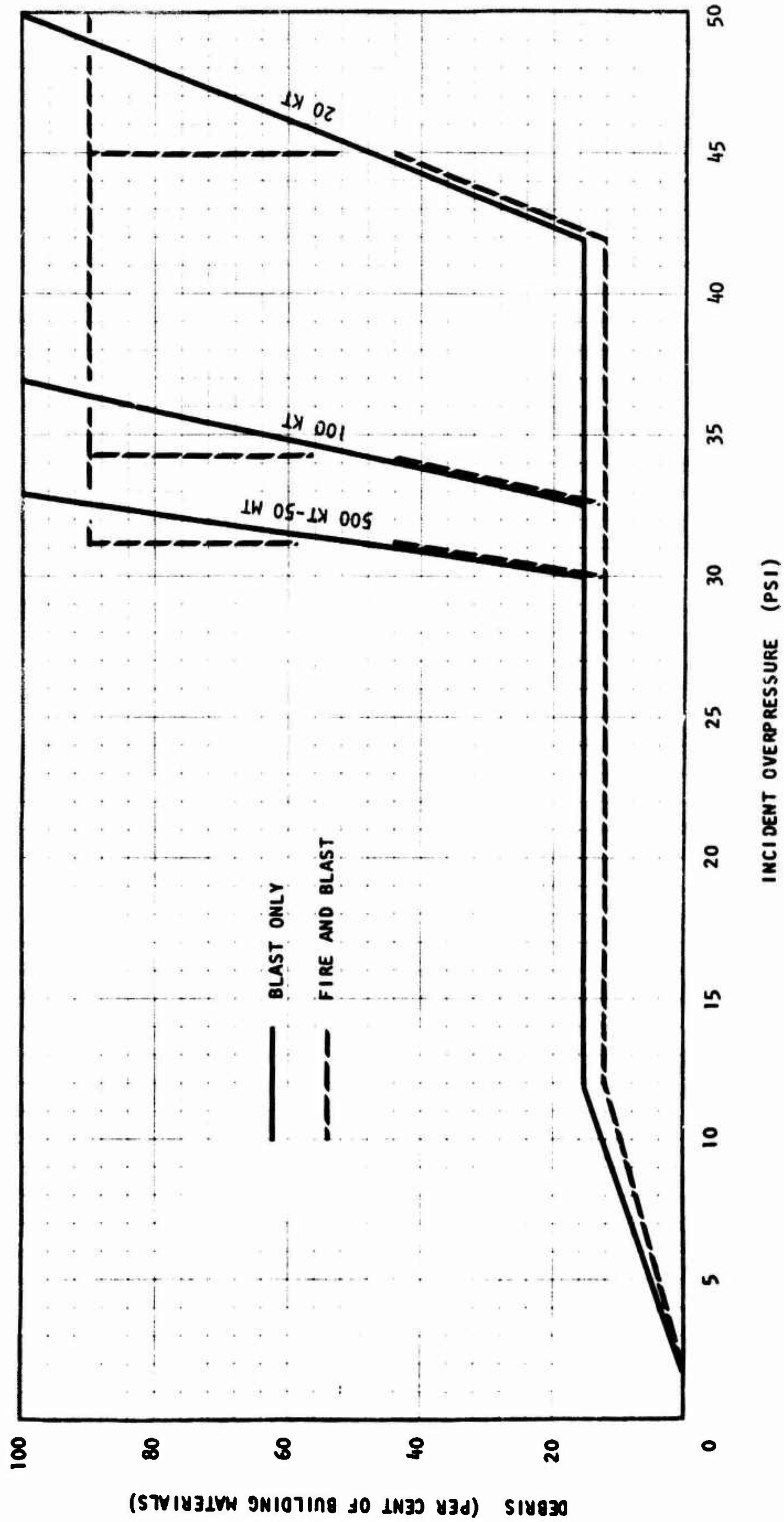

Fig. B-9. Percent Debris vs Overpressure — Multistory Heavy Reinforced Concrete Shearwall Building with Light Interior Panels

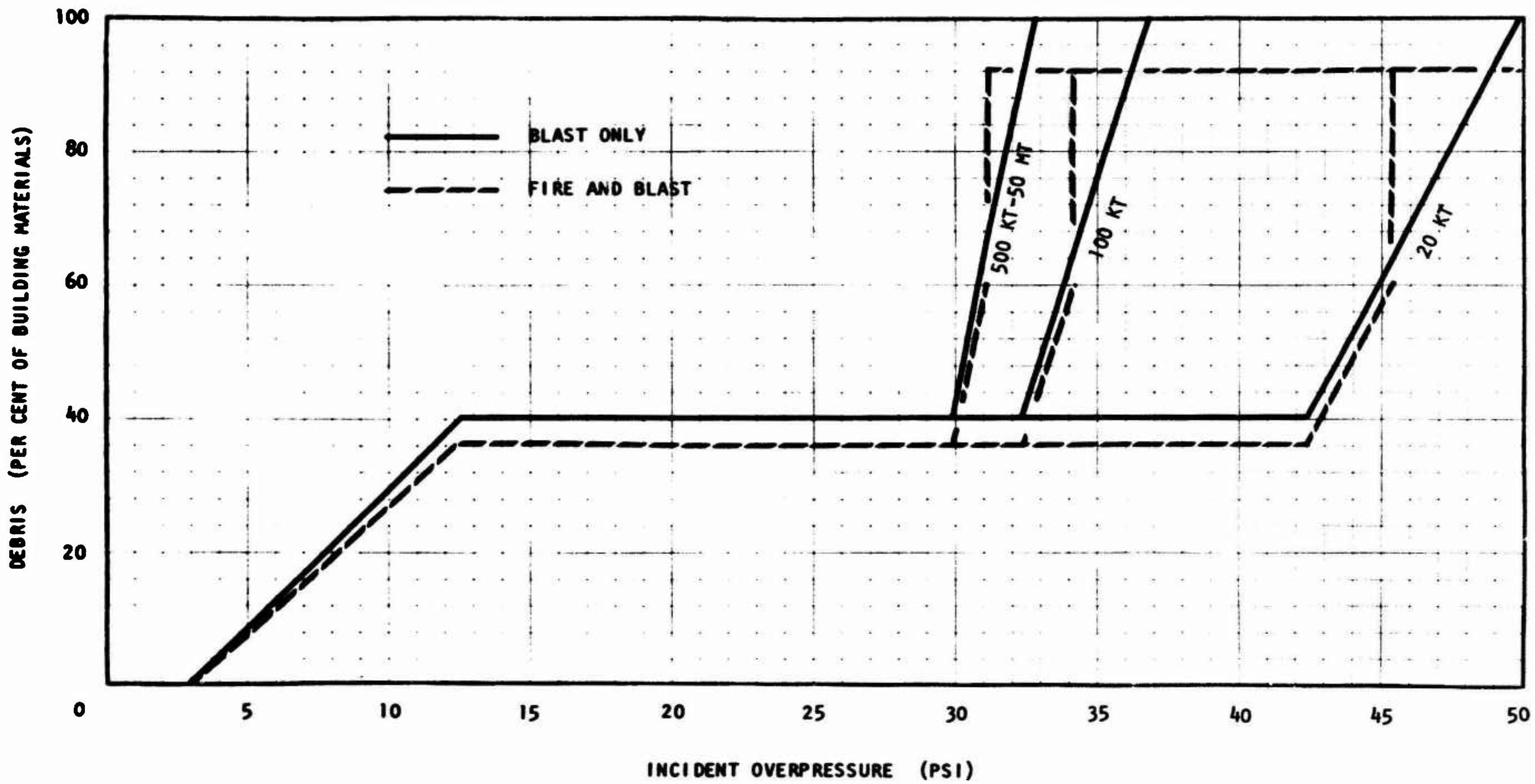

Fig. B-10. Percent Debris vs Overpressure — Multistory Heavy Reinforced Concrete Shearwall Building with Masonry Interior Panels

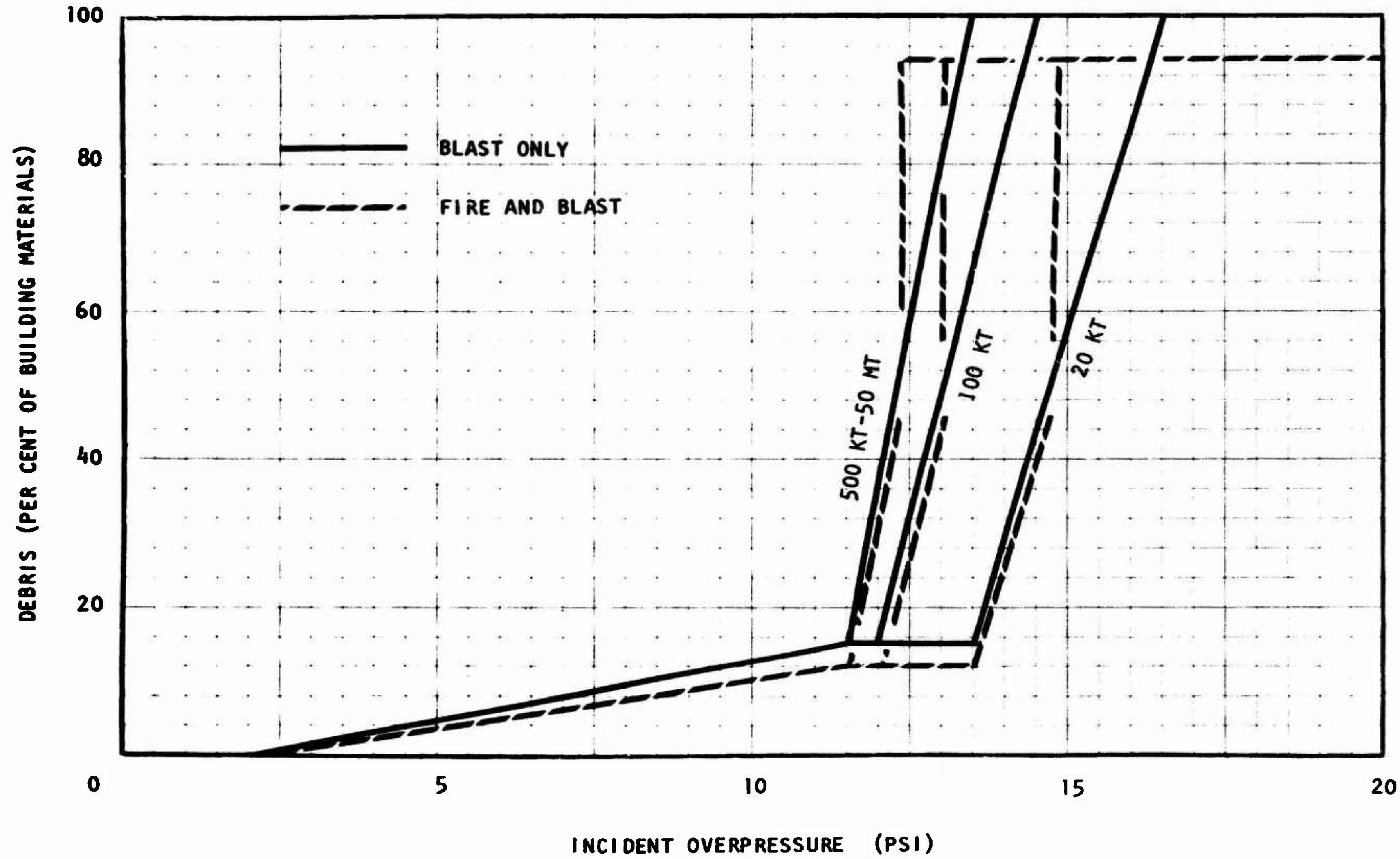

Fig. B-11. Percent Debris vs Overpressure — Multistory Reinforced Concrete Shearwall Building with Light Interior Panels

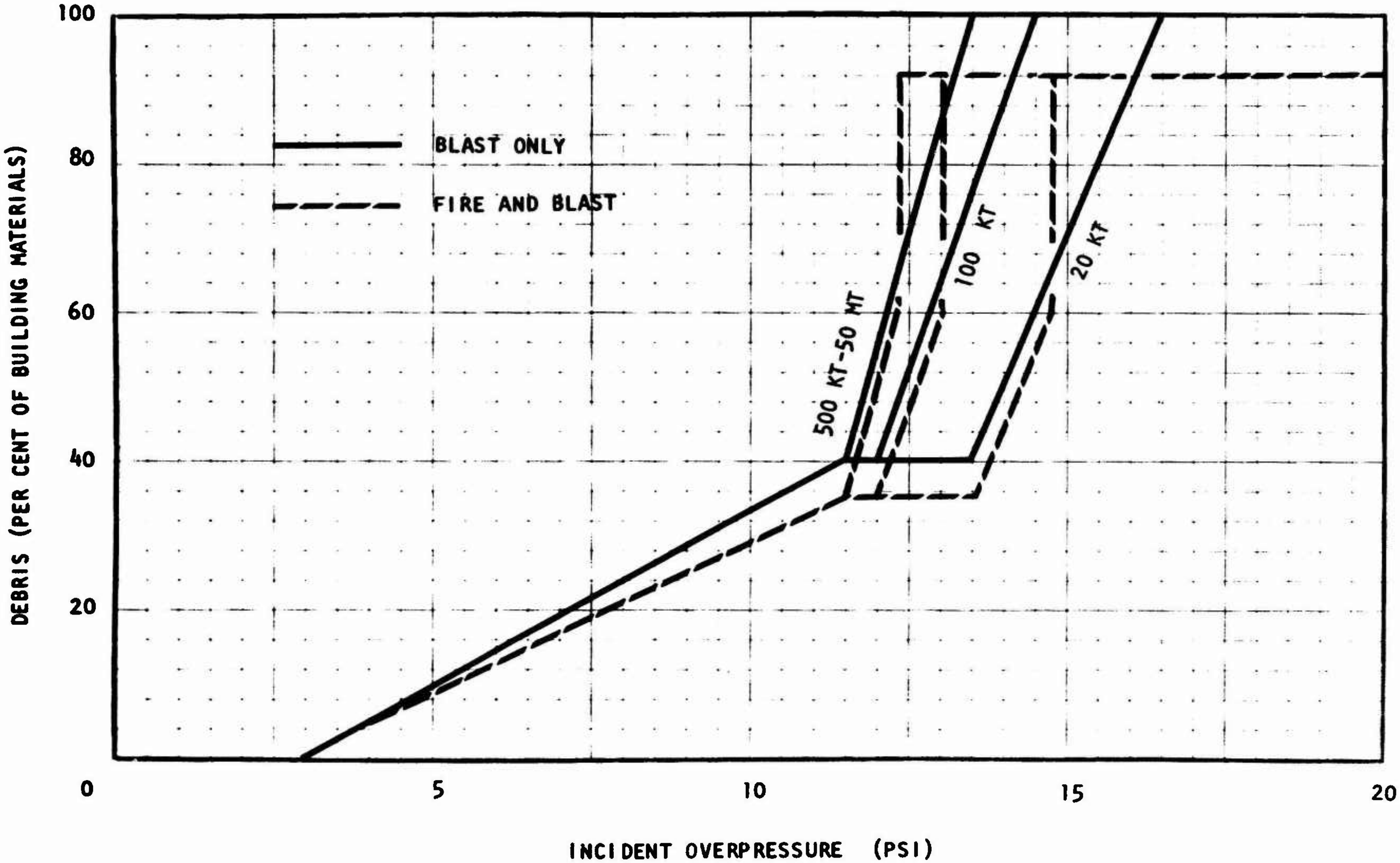

Fig. B-13. **Percent Debris vs Overpressure — Multistory Reinforced Concrete Shearwall Building with Masonry Interior Panels**

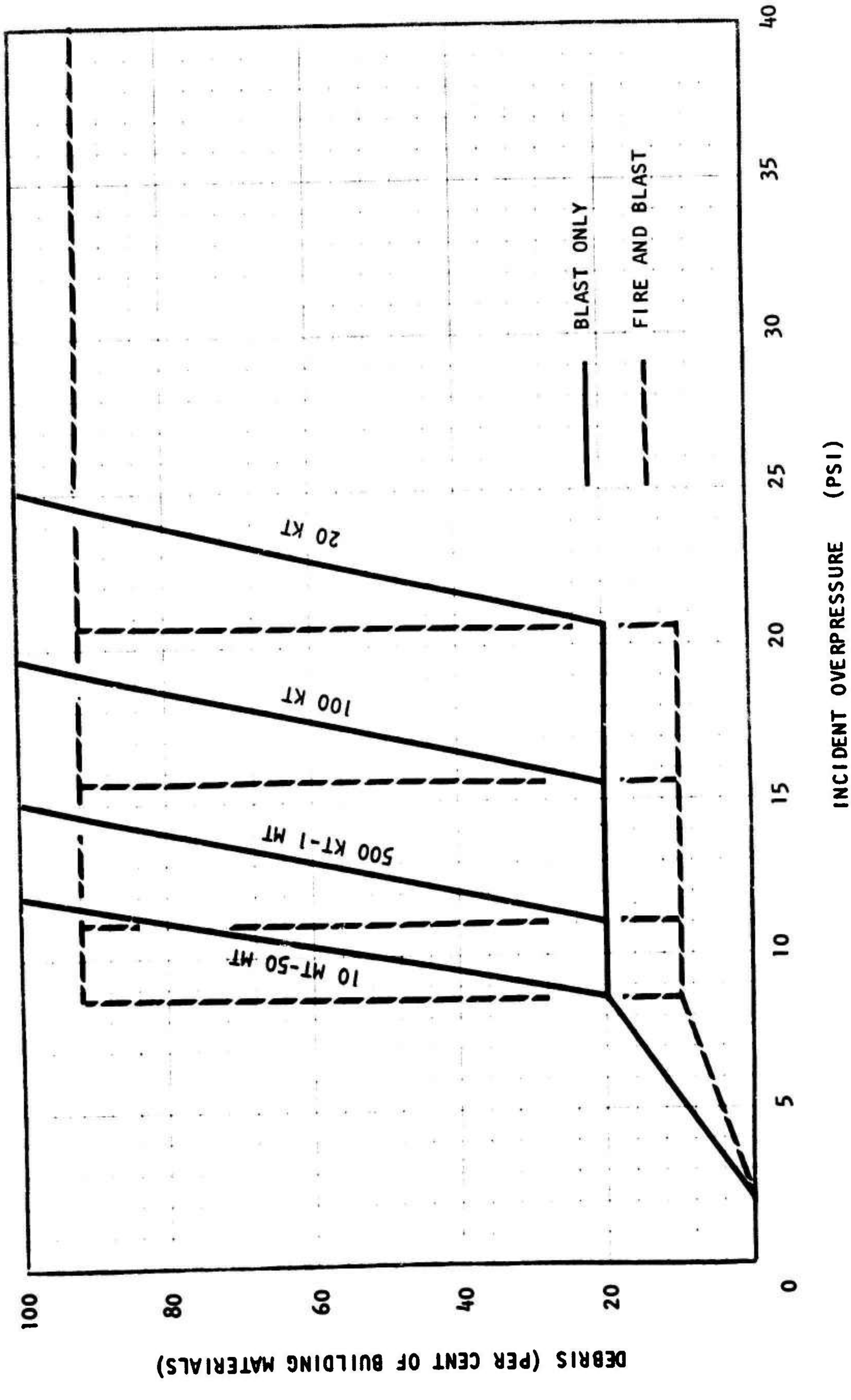

Fig. B-13. Percent Debris vs Overpressure - Multistory Steel or Reinforced Concrete Frame Building with Light Exterior Panels - Non-Earthquake Design

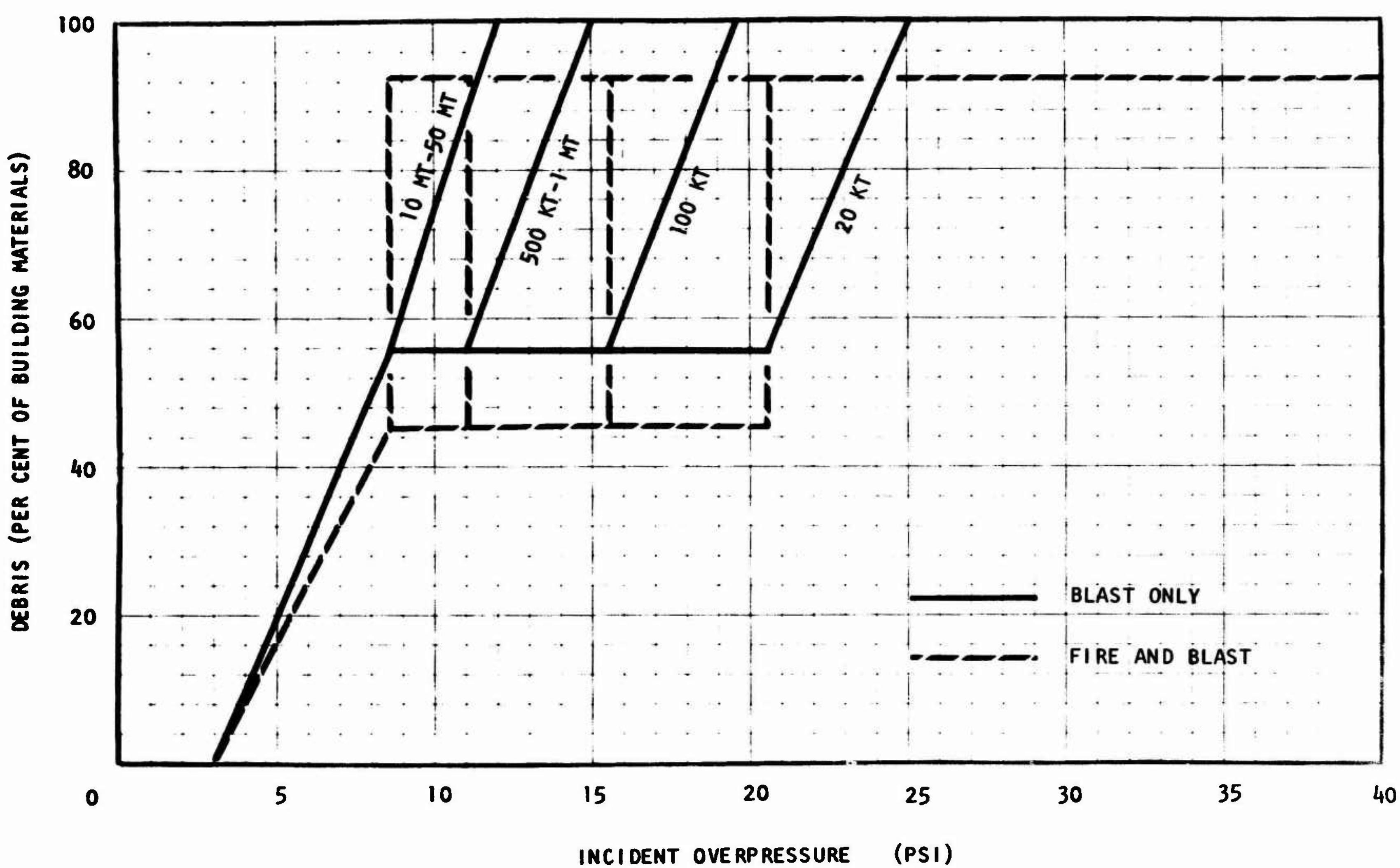

Fig. B-14. Percent Debris vs Overpressure – Multistory Steel or Reinforced Concrete Frame Building with Masonry Exterior Panels - Non-Earthquake Design

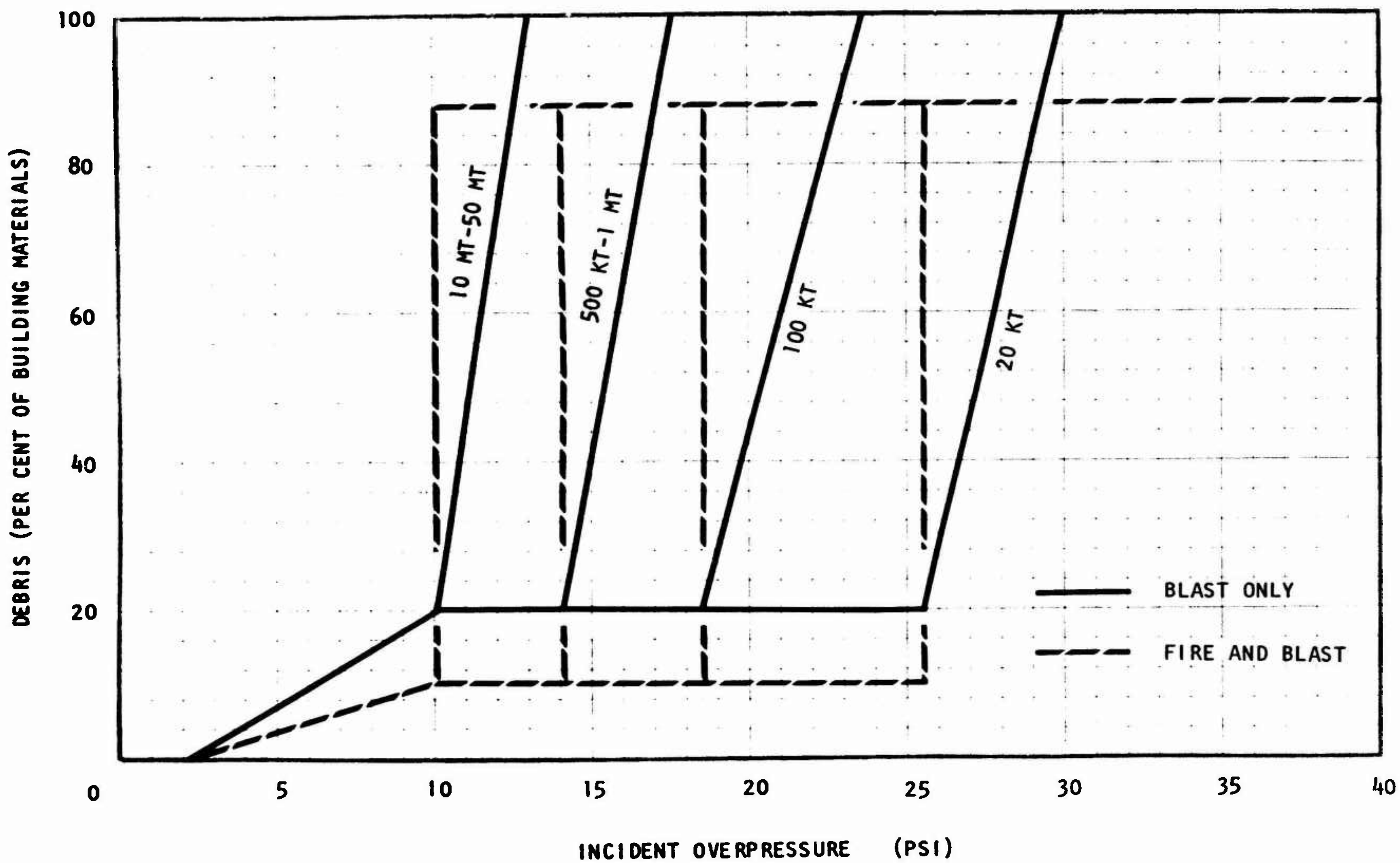

Fig. B-15. Percent Debris vs Overpressure — Multistory Steel or Reinforced Concrete Frame Building with Light Exterior Panels - Earthquake Design

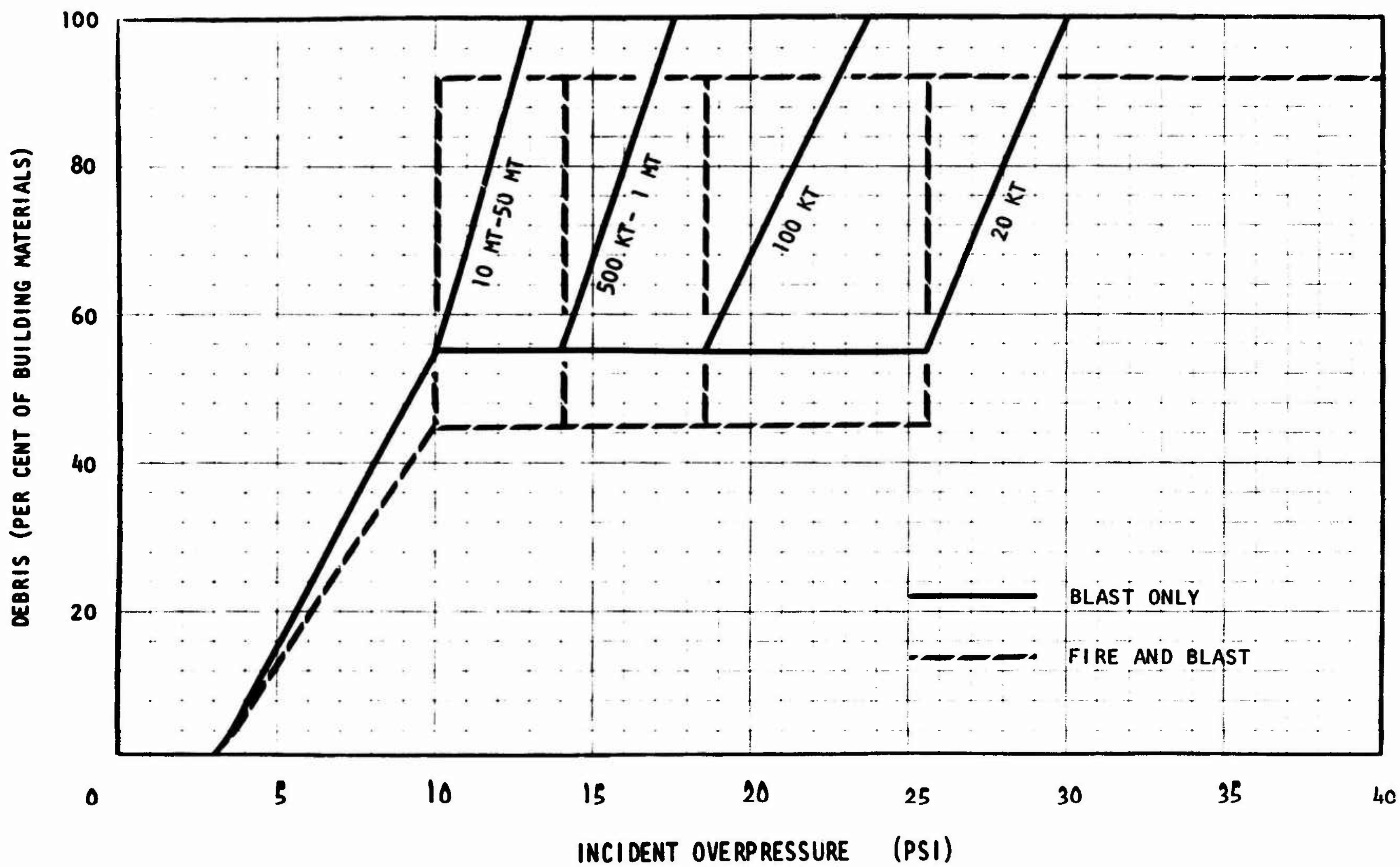

Fig. B-16. Percent Debris vs Overpressure — Multistory Steel or Reinforced Concrete Frame Building with Masonry Exterior Panels - Earthquake Design

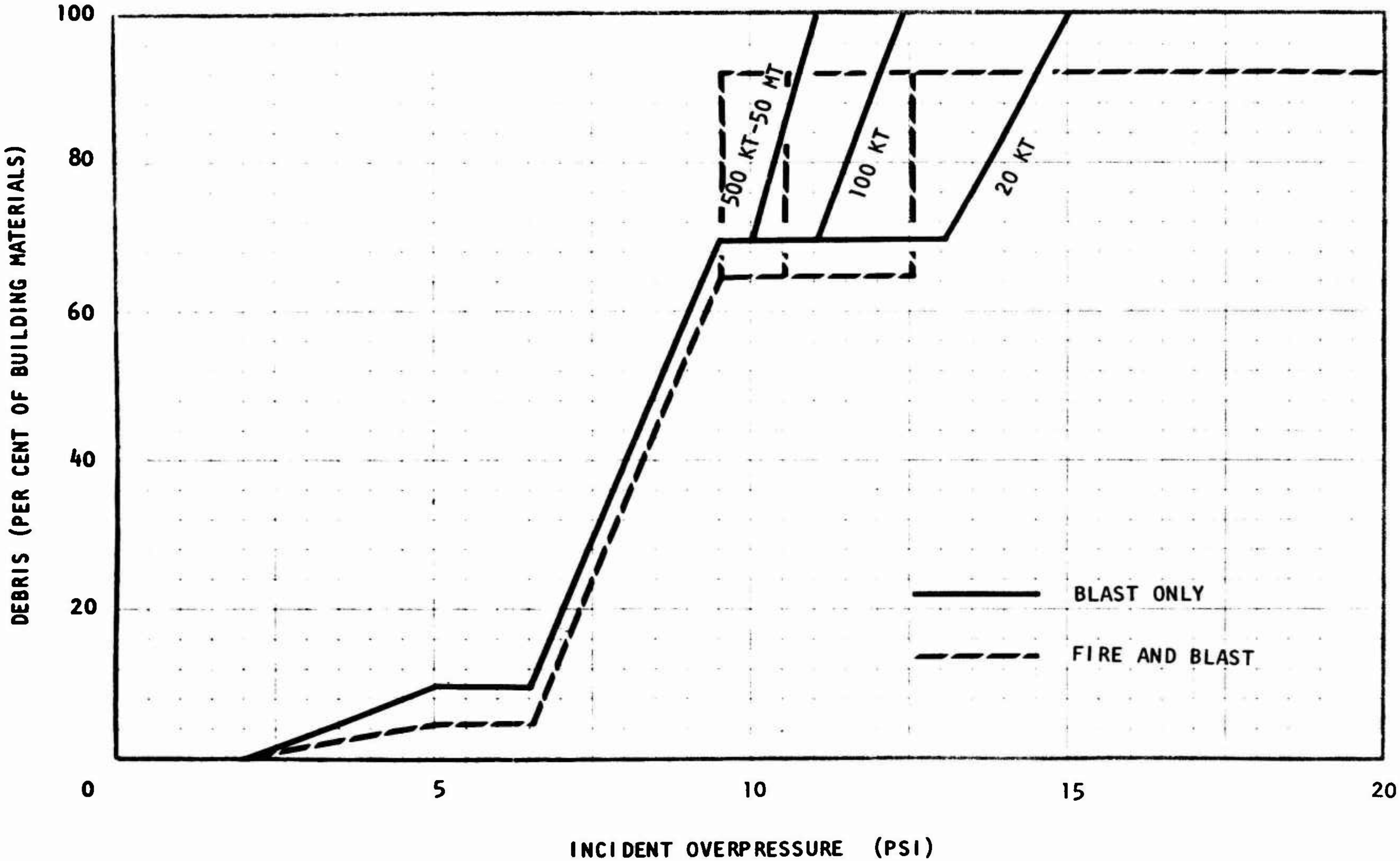

Fig. B-17. Percent Debris vs Overpressure — Light Reinforced Concrete Shearwall Building with Concrete Roof and Light Interior Panels

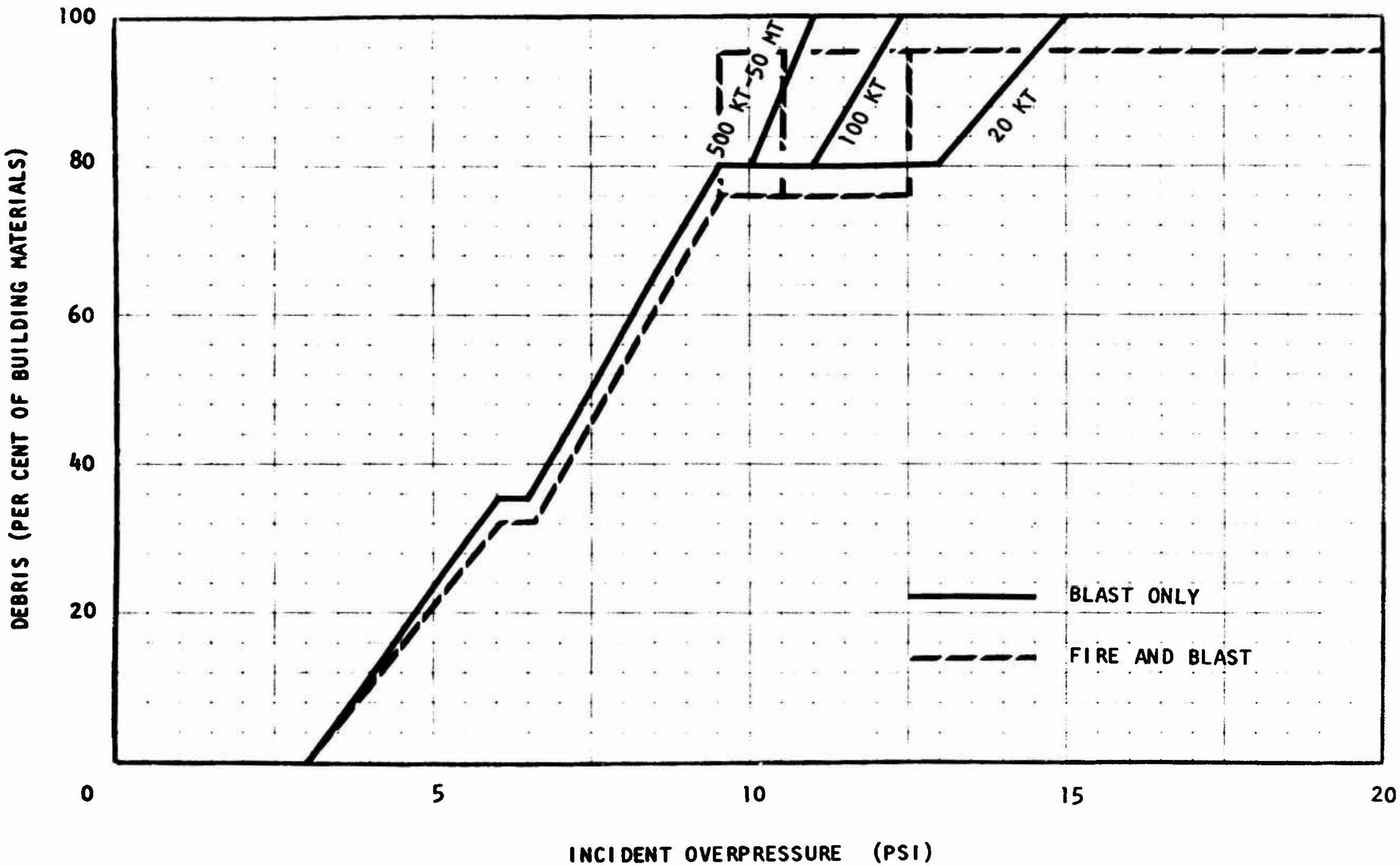

Fig. B-18. **Percent Debris vs Overpressure — Light Reinforced Concrete Shearwall Building with Concrete Roof and Masonry Interior Panels**

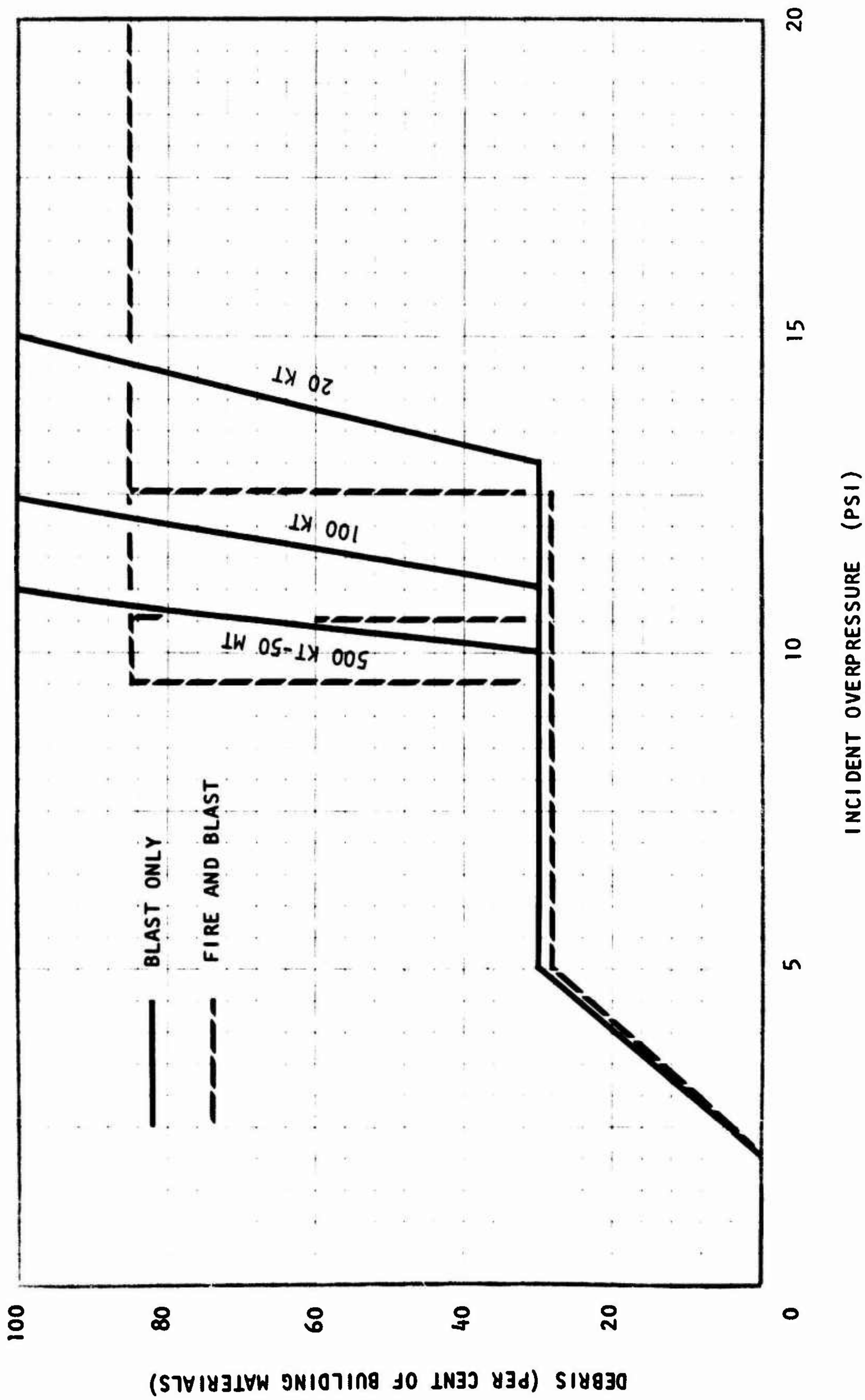

Fig. B-19. Percent Debris vs Overpressure – Light Reinforced Concrete Shearwall Building with Mill-Type Roof and Light Interior Panels

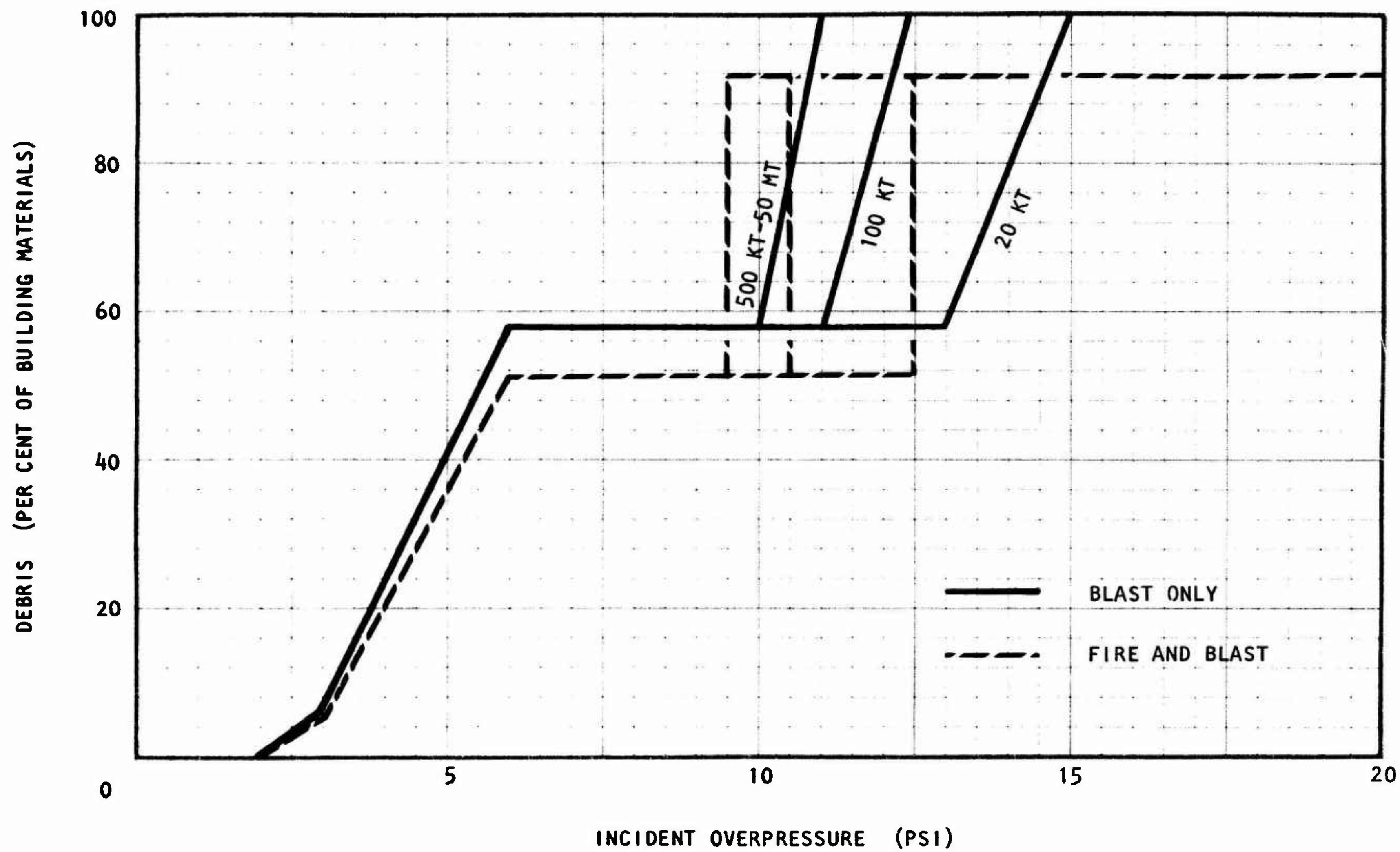

Fig. B-20. Percent Debris vs Overpressure — Light Reinforced Concrete Shearwall Building with Mill-Type Roof and Masonry Interior Panels

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URS 686-4
URS Systems Corporation, Burlingame, California
June 1968 104 pp. Contract No. 12471(6300A-310)
Work Unit 3312B

UNCLASSIFIED

This report is a continuation of research into the prediction of debris depths resulting from a nuclear attack. It also contains an application of the debris prediction method to Albuquerque in support of the Five-City Study.

The Five-City work consists of predicting debris depths and building damage for the city of Albuquerque. The debris depth predictions are presented in reduced scale in this report, and are in the Five-City Study Data Bank in the standard 1:24000 scale. The building damage predictions are in the Data Bank as a seperate document, with examples included in this report.

Damage predictions for various categories of structures and for several attack conditions were furnished to The Dikewood Corporation, and are tabulated herein together with a correlation of URS categories with Dikewood categories.

The debris charts were expanded to cover a larger number of weapon yields – from 20 kt to 50 Mt. The debris prediction for the wood-frame building category was examined to determine whether or not the debris production is independent of weapon yield, as has been assumed.

The debris prediction model was programmed for use with a digital computer, which greatly increases the efficiency of the debris prediction process. An explanation of the program is included in the report.

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Work Unit 3312B

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This report is a continuation of research into the prediction of debris depths resulting from a nuclear attack. It also contains an application of the debris prediction method to Albuquerque in support of the Five-City Study.

The Five-City work consists of predicting debris depths and building damage for the city of Albuquerque. The debris depth predictions are presented in reduced scale in this report, and are in the Five-City Study Data Bank in the standard 1:24000 scale. The building damage predictions are in the Data Bank as a seperate document, with examples included in this report.

Damage predictions for various categories of structures and for several attack conditions were furnished to The Dikewood Corporation, and are tabulated herein together with a correlation of URS categories with Dikewood categories.

The debris charts were expanded to cover a larger number of weapon yields – from 20 kt to 50 Mt. The debris prediction for the wood-frame building category was examined to determine whether or not the debris production is independent of weapon yield, as has been assumed.

The debris prediction model was programmed for use with a digital computer, which greatly increases the efficiency of the debris prediction process. An explanation of the program is included in the report.

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13. ABSTRACT

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